Changes in the Chehalis Floodplain – 1938-2013

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Executive Summary: *Introduction*: We analyzed the Chehalis floodplain using change detection methods to describe habitat and habitat change trajectories, especially for major aquatic and non-aquatic habitat classes, to inform the Aquatic Species Restoration Plan and potential future restoration efforts in the floodplain.

Methods: Habitat analysis encompassed the Chehalis 100-year floodplain plus 100 m (328 ft) using aerial photography over the 1938-2013 interval. Analysis was based on four sets of images. Sets were from the years 1938, 1975/1978 (a composite), 1999, and 2013. The 1938 set was black and white, the 1970s composite and 1999 were standard color (or red-blue-green [RBG]) images; and 2013 was RBG plus infrared. All sets were late summer/early fall aerial photographs except for 1938, which were winter photographs. We created a baseline cover map from the 2013 data, and hand-digitized all discernable surface water and wetlands for each of the four image sets. We also digitized six categories of change from the three sequential pairs of image dates: 1938-1970s, 1970s-1999, 1999-2013. These six categories addressed gains or losses in three focal land cover categories of interest: agriculture, development and tree canopy. Changes are described both for the entire floodplain, and for 10 floodplain segments partitioned by major tributaries (these segments are sequentially numbered in an upstream direction 1 to 10).

Results: The 2013 baseline map defines a 57,325-acre (ac) (23,199-hectare [ha]) floodplain. Standardized as acres/river mile (ac/RM) (hectares/kilometer [ha/RKm]), floodplain segments generally decreased over six-fold in area as one moves upstream (from 790 ac/RM [199 ha/RKm] to 132 ac/RM [33 ha/RKm]). However, a marked decrease in area occurs above the South Fork Chehalis River (from 375 ac/RM [94 ha/RKm] to 181 ac/RM [46 ha/RKm]). In this summer aerial photograph, we estimated that 10.2% of the entire floodplain area (5,854 ac [2,369 ha]) was aquatic habitats. Half of that area was the main channel of the Chehalis River (5.0%, 2,868 ac [1,161 ha]). Much of the remainder was in floodplain wetlands or off-channel aquatic habitats (3.4%, 1,939 ac [785 ha]) with the rest of aquatic habitats as tributary streams (1.4%, 800 ac [324 ha]) or human-built ponds (0.4%, 247 ac [100 ha]). Based on absolute area, main channel and tributary stream classes were disproportionately over-represented in the downstream-most segment (between the Highway 101 bridge in Aberdeen and the Wynoochee River); specifically, 38.9% and 69.8%, respectively, of the entire area of these two aquatic habitat classes in the floodplain was recorded in this segment. Also based on absolute area, the wetland class was disproportionately over-represented in Segment 3 (between the Satsop River and Porter Creek), specifically, 37.4% of the entire area of wetlands in the floodplain was in this segment. Further, nearly two-thirds (65.8%) of wetlands in the entire floodplain occurred between the Wynoochee and Black Rivers (Segments 2, 3, and 4). Based on scattered ground truth checks, we underestimated the overall 2013 summer

area of aquatic habitat by ~1% of the entire floodplain area; most of that underestimate results from tree canopy concealing aquatic habitats in the tributary stream and wetland classes.

In descending order of areal importance in the 2013 baseline map, dominant habitat classes were herbaceous, forested, and shrub/small tree classes, which represented, respectively, 37.1% (21,243 ac [8,597 ha]), 23.1% (13,219 ac [5,350 ha]), and 19.4% (11,143 ac [4,509 ha]) of the floodplain area. Also based on ground-truthing, the herbaceous class and roughly half of the shrub/small tree class was some form of pasture (extant or fallow), or herbaceous or shrub crop (e.g., timothy grass or blueberries). The herbaceous habitat class constituted between >29% and <51% of the area in all segments except the down- and upstream-most segments (below the Wynoochee River and above Elk Creek). The shrub/small tree habitat class was 36.0% of the segment area only in the downstream-most segment and >11.0% but <19.6% in all other segments. The forested habitat class was >42% of the segment area only in Segments 5 (Black River to Scatter Creek) and 10 (above Elk Creek), and ranged from >9% to <32% in all other segments. The area of the forested habitat class is overestimated at a level approximating the underestimates in aquatic habitats previously discussed. Remaining habitat classes (bare ground, built [i.e., developed], and sand/gravel), constituted, respectively, 5.6% (3,230 ac [1,307 ha]), 3.6% (2,077 ac [841 ha]), and 0.5% (273 ac [110 ha]) of the floodplain area.

Mapped aquatic habitat footprints revealed three key wetland and stream patterns. First, the extent of off-channel wetlands is most prominent in Segment 2 (Satsop River to Porter Creek). Second, wetland losses after 1970s appear limited. Large losses prior to the 1970s are suspect, but the winter timing of the 1938 aerial set prevents effective interpretation of wetland losses in the 1938-1970s interval. Third, the Chehalis main channel and some its major tributaries prominently migrate (laterally) in selected areas, which include:

1) the portions of the Satsop and Wynoochee Rivers in the Chehalis floodplain;
2) the Chehalis main channel above the Wynoochee River;
3) up- and downstream of the confluence of the Black and Chehalis Rivers;
4) up- and downstream of the confluence of Bunker Creek and the Chehalis River;
5) upstream of the confluence of the South Fork Chehalis River and Chehalis River.

Despite the preponderance of a significant amount of off-channel habitats in the floodplain between the Skookumchuck and Newaukum Rivers, which is along the Interstate 5 corridor, migration of the Chehalis main channel in this reach appears very limited.

We observed considerable change in the three land cover categories in the overall floodplain. In particular, agricultural land showed a marked net increase over 1938-1970s interval (50 ac/yr [20.2 ha/yr]), but a substantial net decrease over the 1970s-2013 interval (-26 ac/yr [-10.5 ha/yr]). In contrast, net changes in forest canopy over the same time periods were almost the inverse; forest canopy showed a marked net decrease over the 1938-1970s (-58 ac/yr [23.5 ha/yr]), but a substantial net increase over the 1970s-2013 interval (17 ac/yr [6.9 ha/yr]). In contrast, developed area uniformly increased over the study period, though the increase in the 1970s-2013 interval (19 ac/yr [7.7 ha/yr]) was over double that of the 1938-1970s interval (8 ac/yr [3.2 ha/yr]). However, the overall pattern in the latter net changes conceals an important difference in the changes between

the lower and upper Chehalis floodplain (i.e., downstream versus upstream of the Black River). In particular, an extreme net decrease in forested canopy occurred on the lower Chehalis floodplain over the 1938-1970s interval (-67 ac/yr [-27.1 ha/yr]), whereas a modest net increase in forested canopy occurred on the upper Chehalis over the same period (9 ac/yr [3.6 ha/yr).

Conclusions: Our analysis revealed that the 2013 summer extent of aquatic habitats cover $^{1}/_{10}$ of the Chehalis floodplain; roughly one-third of that area exists in off-channel habitats important to stillwater biota. About $^{1}/_{20}$ of the floodplain is developed, and combined vegetated land classes (herbaceous, shrub/small tree, and forested) collectively comprise 80.7% of the entire floodplain. Wetland losses after the mid-1970s seem limited, but pre-1970s losses are difficult to interpret because of the winter season timing of the 1938 aerial series. Moreover, changes in wetland and tributary area should be interpreted with caution given both inter-year variation in wetness and the error tradeoff between canopy and the wetted footprint resulting from canopy concealing wetland area. However, the historical aerial series is useful for identifying significant lateral stream migration in the Chehalis floodplain, which seems restricted in selected focal areas. Dramatic change in land cover has occurred since 1938, including marked increases in land converted to agriculture prior to the 1970s, but significant land shifted out of agriculture thereafter; marked declines in forested land prior to the 1970s, but significant increases in forested land thereafter; and relatively low rate of development prior to the 1970s, but a more than doubling of that rate thereafter.

Next Steps: Our analysis identified patterns. Those patterns should be linked to activities or processes that affect channel migration, wetland loss or gain, of the gain or loss of other land cover classes in order to examine the level of correspondence with observed patterns and provide useful interpretations. For example, the extent of channel migration could be quantified from this mapping and associated to areas of bank hardening, channel incision, or other conditions or processes that can alter channel migration. Refinement of changes in the land cover maps will improve identifying trends because the baseline maps now exist to facilitate such analysis; in particular, availability of Lidar coupled to RBG and IR layers for maps produced since 2013 will enable detecting change at a more resolved level. Nonetheless, our analysis makes it clear that some level of ground-truthing will be needed to ensure resolution, particularly for wetlands and tributaries, where areas involved are frequently smaller than those of other land cover classes. Evaluation of trends from conducting high resolution change detection as new versions of the NAIP map appear (now expected every three years) should be considered because it could provide fundamental high-level monitoring to the ASRP at a what is likely a reasonable cost.

Introduction

Examination of landscape patterns over time have become a fundamental part of identifying changes and trends at regional and global scales (Turner et al. 2007, Pierce 2015). The Aquatic Species Restoration Plan (ASRP) currently under development for the Chehalis system is a basin-level plan (J. Allegro, M. Hunter, pers. comm.), and hence, has a regional scale that lends itself to

landscape-level remote-sensing analysis. For this reason, we began an effort to examine landscape patterns in the Chehalis floodplain from available aerial photography.

Our effort had two fundamental goals: 1) To provide a baseline map to describe current habitat conditions and patterns across the Chehalis floodplain; and 2) To describe changes extending back in time to the earliest aerial photographs available. A focal part of this effort addressed aquatic habitats because it was designed to inform, support, and be integrated with analyses involving biotic sampling of off-channel habitats in the Chehalis floodplain.

Methods

Floodplain Definition and Segmentation

We defined the floodplain as a line encompassing the 100-year FEMA (Federal Emergency Management Agency) floodplain plus 100 m (328 ft) that extends from the Highway 101 bridge in Aberdeen to the location of the proposed dam above Pe Ell. We divided this floodplain, which encompasses 114 RM (183 RKm) of the Chehalis River main channel, into 10 segments bounded by major tributaries (Fig. 1).

Image Creation

Baseline Image: We derived the baseline image from US 2013 National Agriculture Imagery Program (NAIP) data. This is a standardized orthorectified set of images taken in late summer that had been pre-assembled into the appropriate image. The image has four-bands, standard red-blue-green (RGB) plus infrared (IR). We also calculated the Normal Difference Vegetation Image (NDVI) as a fifth band, and obtained a height layer from the Washington Department of Natural Resources (WDNR) from overlapping portions of supplemental NAIP data using digital photogrammetry. We subtracted a LIDAR bare-earth image from the height layer to generate canopy height for the subsequent habitat classification model.

Historical Images: We chose historical images from three sets of dates. Our basis for date selection was to ensure maximal coverage of the Chehalis floodplain, enough separation in time between images to enable detecting significant change, and that the oldest image set was from the earliest date available. The first and second of these criteria led us to select an image set from the 1970s and 1999; and the third criterion resulted in selecting 1938 imagery. The floodplain images created for all these dates were from scanned aerial photographs lacking geographic information.

The oldest (1938) image set, obtained from the Army Corp of Engineers (Seattle District), was taken during the months of January and February. The image was created by manually georeferencing over 300 individual scanned aerial single-band gray-scale images using the georeferencing tools available in ArcGIS 10.2.

The 1970s floodplain image (obtained from Washington Department of Natural Resources [DNR]),, a standard RBG three-color image (no IR), was created from a composite of 1975 and 1978 images because neither year had complete floodplain coverage. All this imagery was late summer. The 1970s image was initiated using Agisoft PhotoScan™ software (Agisoft LLC, St.

Petersburg, Russia). PhotoScan™ automatically fits image overlaps and warps them into a seamless image. Only small subsections of the study area were satisfactorily combined using this method. To complete the whole image for the study area, the remaining sections were manually georeferenced similar to the 1938 image.

The 1999 image (also obtained from DNR), also standard RBG, was created using the same process as the 1970s image.

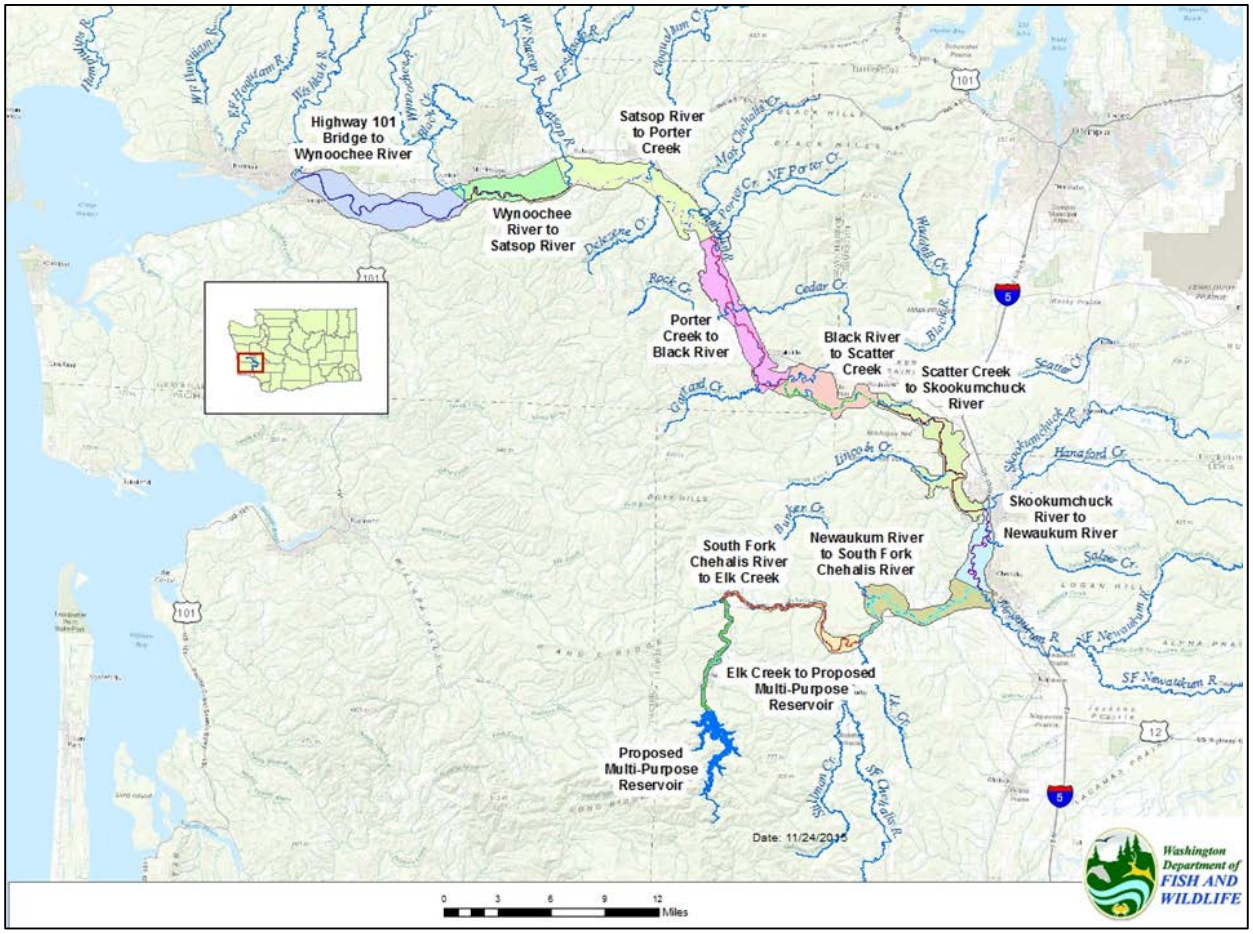


Figure 1. Chehalis River floodplain with the segments (color-differentiated) used in our analyses. Floodplain boundary is based on the 100-year flood (FEMA definition) plus 100 meters. Inset map shows the position of the Chehalis River in Washington State. Area and distance data for the floodplain segments shown are provided in Table 1.

Habitat Characterization

Baseline Habitat: The primary data sets for the 2013 land cover modeling were the baseline 2013 NAIP image with its LIDAR-derived height layer and supplemental height-informing NAIP imagery as assessed with digital aerial photogrammetry. Ancillary vector data also used included a roads layer from Geolib (the WDFW spatial database), and the National Wetlands Inventory

(NWI) and National Hydrography Dataset (NHD) area and line features. Generating the land cover classification required three major initial steps:

1) An unsupervised classification was performed on vegetation and non-vegetation portions of the 2013 image as separated by NDVI values. The statistical classes derived from the unsupervised classification were relabeled to the useable land cover classes of Bare Ground, Built, Shadow, Gravel, Water, and three Vegetation classes (Fine, Medium, and Coarse). This comprised the pixel-based classification.
2) Segmentation was performed on the imagery stack to generate a set of about 475,000 polygons with relatively homogenous land cover units. About 2000 land cover sample points were generated to train a Classification and Regression Tree (CART) statistical model of land cover polygons. We used eCognition software (Trimble, Inc., Sunnyvale, California) to train and implement the CART model.
3) A set of rule-based classifications followed the CART model that used the raster model as additional data pertaining to a final classification. All polygons were attributed with the proportion of the polygon in the raster model comprising one of the raster classes. As such a "Coarse Vegetation" polygon derived from the segmentation model might have had a distribution of different classes in the raster model (e.g., 75.2% coarse vegetation, 7.5% shadow, 4.1% water, 13.2% ground). Polygons were also attributed with the mean height as derived from Digital Aerial Photogrammetry and the relative distance to multiple ancillary data sources including roads, and NHD and NWI features. The combination of CART class, relative raster class proportions, height and other proximal factors were considered in a hierarchical battery of over 400 logic rules.

Fourteen land cover classes existed in an initial set of polygons from this exercise (**Table 1**). Most polygons had class labels beginning with "Final", which means they were assessed and made it through one or more rules in the third classification step. Remaining land cover classes were preliminary and collectively covered over 400 ac except for Gravel, a category considered near-final. No-Data and Bad-Height cover class polygons were mostly tiny edge polygons that overlapped boundaries or places lacking LIDAR needed to model height. The Intensity Low class was mostly shadows and a few hard-to-characterize water-surface polygons. Several days were spent writing more rules to classify CART polygons over this initial classification. The initial rule set was developed over several months and was expanded from a prior unpublished land cover mapping project.

We then engaged in a suite of refinements collectively involving some kind of reclassification, dissolution or deletion (**Table 2**). In particular, the Bad Height cover class was dissolved and produced five polygons that actually overlapped the floodplain map; all other Bad Height cover class polygons and all No Data were edges, which were all deleted. All 222 Water Conflict polygons and all Built Blue Green, Built Brown Red, Intensity Low, and Gravel polygons >0.3 ac in size were individually examined and moved to other cover classes. We also reclassified Final Built polygons >0.3 ac that overlapped the NHD area buffer. Five reclassified polygons from the aforementioned suite were moved into Manure Ponds, a new cover class. In a final reclassification

effort, all remaining Built Blue Green (i.e., all those ≤0.3 ac) were moved into Final Fine Vegetation, all remaining Built Brown Red and Gravel (i.e., all those ≤0.3 ac for both) were moved into Final Ground, Final Built Brown Red was moved into Final Built, and Intensity Low was renamed Final Shadow.

Table 1. Land Cover Polygon Classification and Distribution from the Initial Rule-Based Classification following the CART model.

#	Polygon Name	Number of Polygons	Collective Area (ac)
1	Bad Height	10,566	40
2	Built Blue Green	3,636	140
3	Built Brown Red	900	31
4	Final Built	28,879	2,324
5	Final Built Brown Red	3,571	175
6	Final Coarse Vegetation	176,669	14,187
7	Final Fine Vegetation	58,710	22,328
8	Final Ground	20,218	3,297
9	Final Medium Vegetation	145,288	12,380
10	Final Water	13,334	4,672
11	Gravel	4,998	509
12	Intensity Low	2,961	188
13	No Data	4,466	5
14	Water Conflict	222	14
	Totals	474,418	60,290

Table 2. Refined Land Cover Polygon Classification and Distribution.

#	Polygon Name	Number of Polygons	Collective Area (ac)
1	Bad Height	5	37
2	Final Built	33,306	2,564
3	Final Coarse Vegetation	176,687	14,195
4	Final Fine Vegetation	62,491	22,496
5	Final Ground	25,198	3,734
6	Final Medium Vegetation	145,302	12,384
7	Final Shadow	2,682	133
8	Final Water	13,715	4,738
9	Manure Pond	5	2
	Totals	459,391	60,283

We then simplified the polygon matrix via dissolution of adjacent polygons in the same cover class, which reduced the polygon count from 459,391 to 70,919.

In an independent exercise, we hand-digitized the Chehalis River main channel and all visibly discernable surface water and wetlands on the 2013 NAIP base map. We used information obtained on the ground in 2014 and 2015 to assist this digitization process. In particular, the latter information helped determine the tradeoff between wetlands, channels or streams occluded by the Coarse (tree) Vegetation cover class.

The hand-digitized Chehalis River main channel, discernable surface water and wetland (collectively water features) were then used to erase areas of the original land cover polygons. The hand-digitized water features were appended to the land cover polygons, filling the original water feature gaps. These have a subclass of digitized polygons to distinguish them. The 2013 Main Stem was use to clip out the original polygons in the digitized Main Stem area. From these clipped polygons, the Final Built and Final Ground were separated into a separate layer and dissolved into single polygons and labeled Sand/Gravel. The Final Vegetation cover classes were separated into a different layer. Polygons with areas <0.04 were deleted and were overwhelmingly comprised of outer edge slivers consisting of 2-10 pixels in a row. No internal gaps were detected from this process.

Finally, we simplified nomenclature across classes. The terminology of Fine, Medium and Coarse Vegetation is taken from the current literature on high-resolution mapping and refers to the texture indicative in different vegetation types. Fine Vegetation is predominately herbaceous cover and Coarse Vegetation is predominately tree canopy. Between these two endpoints lies everything else: tall grasses, high crops, shrubs, chaparral, small trees and so forth. Medium Vegetation is meant to capture this and thus is really indicative of non-grass, non-tree. However, to simplify our nomenclature and clarify relationships, we changed these model class names from Fine, Medium and Coarse to Herbaceous, Shrub/Small Tree and Forested. Water was replaced with our digitized classes of Main Channel, Stream (includes tributaries), Man-made Pond and Wetlands. Erroneous built polygons in the digitized Main Channel and Streams were relabeled Sand/Gravel. The Bad height and Final Shadow were simply reclassified as Indeterminate.

Historical Habitat: We also hand-digitized each of the three historical images for wetland and stream categories identical to the 2013 baseline image**.** Digitizing wetlands from 1938 was difficult due to the nature of gray-scale imagery and some image degradation caused by the mosaicking process. However, many wetlands only recorded in 1938 had discernable surface outlines in later years, which would seem to indicate depressions that might be more frequently wet in winter, when the 1938 image was captured.

Habitat Change

Our original plan was to digitize habitat changes from three pairs of image dates: 1938:1970s, 1970s:1999 and 1999:2013. However, lack of 1999 imagery for the two river segments below the Satsop River (Segments 1 and 2) led to our comparing two pairs of image dates for those segments: 1938:1970s and 1970s:2013. Further, to enable comparisons among the maximum number of

segments, we conducted the latter comparison across all 10 segments in addition to the original three-date pair comparison for the eight segments above the Satsop River. We arbitrarily elected to use the year 1975 for the basis of comparing change between the 1970s image and other image dates. Additionally, scattered local gaps in aerial coverage (Appendix I) required that we report changes as net annual change between date pairs as acres per year (hectares per year).

The aforementioned comparisons focused on increases or decreases in five habitat categories: Agriculture (land used in some kind of agriculture), Canopy (forested habitat), Development (buildings and impervious surfaces), Wetlands and Tributaries, and the Chehalis River main channel. For this analysis, Wetlands and Tributaries combined the digitized Streams (representing tributaries) and Wetlands categories because of the difficulty with distinguishing the two on earlier images. Further, winter timing of the 1938 image prevented areal comparison of this image with the remaining image dates for wetlands and Chehalis River tributaries and the Chehalis River main channel. However, this image remained useful for characterizing channel migration. Further, significant channel migration in several of the major tributaries led us to use the 1938 midline of the major tributaries as the segment boundaries for comparison among image dates, and the basis on which all segment areas were calculated.

Results

Land Cover 2013

Overall Floodplain: The 2013 baseline map (**Fig. 1**) defines a 57,325-acre (ac) (23,199-hectare [ha]) floodplain (**Table 3**). Based on river length, flood plain segments vary by approximately two-fold in length (7.7 to 14.4 RM [12.4 to 23.1 RKm]), but nearly an order of magnitude in area (1,118 to 10,344 ac [ha]), largely reflecting a generally decrease in floodplain width as one progresses upstream (**Table 3**). Standardized as acres/river mile (ac/RM) (hectares/river kilometer [ha/RKm]), floodplain segments decreased over six-fold in area as one moves upstream (from 790 ac/RM [199 ha/RKm] to 132 ac/RM [33 ha/RKm]). However, this decrease is area not absolutely continuous; narrowing occurs in the Satsop River to Porter Creek segment (Segment 3) following by slight expansion in the next upstream segment (**Table 3**). Further, based on this standardized measurement, the sharpest decrease in area was between the segments bounding the South Fork of the Chehalis River, reflecting the dramatic narrowing of the floodplain in Segment 9 in the vicinity of RM 95-96 (152.6-154.2 RKm). However, important decreases in floodplain area (i.e., >100 ac/RM [>25.2 ha/RKm]) with progressive upstream position also occurred between Segments 2 and 3, and Segments 6 and 7 (**Table 3**). In part, these reflect pinch points toward the upstream end of Segment 6 (i.e., below Porter Creek), and near the juncture of Segments 6 and 7 (i.e., near the confluence of the Chehalis and Skookumchuck Rivers).

On the 2013 baseline map, three vegetative land cover classes (herbaceous, shrub/small tree, and forested) dominated the floodplain (**Tables 4** and **5**). Collectively, these three vegetation cover classes comprised 79.6% of floodplain area. In descending order of importance, they were herbaceous 37.1% (21,243 ac [8,597 ha]), forested 23.1% (13,219 ac [5,350 ha]), and shrub/small

tree (19.4% (11,143 ac [4,509 ha]). Based on ground-truthing, the herbaceous class and roughly half of the shrub/small tree class was some form of pasture (extant or fallow), or herbaceous or shrub crop (e.g. timothy grass or blueberries). The herbaceous class made up between >29% and <51% of floodplain area in all segments except the down- and upstream-most (Segments 1 and 10; **Table 5**). The shrub/small tree habitat class had 36.0% of the segment area in Segment 1, and represented from 11.1% to <19.6% in all other segments. The forested habitat class was most prominent (>42% of the segment area) in Segments 5 (Black River to Scatter Creek) and 10 (above Elk Creek), and ranged from >9% to <32% in all other segments.

In the 2013 aerial photograph, a late summer image), we estimated that 10.2% of the entire floodplain area (or 5,854 ac [2,369 ha]) was aquatic habitats (Chehalis River main channel, stream (tributaries) and wetlands combined; **Tables 4** and **5**). Half of that area was the main channel of the Chehalis River (5.0% of entire floodplain or 2,868 ac [1,161 ha]). Well over half the remainder was in floodplain wetlands or off-channel aquatic habitats (3.4% of floodplain; 1,939 ac [785 ha]) and the rest as tributary streams (1.4% of floodplain; 800 ac [324 ha]) or human-built ponds (0.4% of floodplain; 247 ac [100 ha]). Based on area, main channel and stream (tributary) classes were disproportionately represented in the downstream-most segment; specifically, 38.9% and 69.8%, respectively, of the entire area of these two aquatic habitat classes in the floodplain was recorded in this segment. The wetland class was disproportionately represented in Segment 3 (Satsop River to Porter Creek); specifically, 37.4% of the entire area of wetlands in the floodplain was in this segment (**Table 4**). Further, nearly two-thirds (65.8%) of wetlands in the entire floodplain occurred between the Wynoochee and Black Rivers (Segments 2, 3, and 4; **Table 4**). Based on scattered ground truth checks, we underestimated the overall summer 2013 area of aquatic habitat by about 1% of the entire floodplain area, which underestimates the overall aquatic footprint by roughly 10%. Most of that underestimate results from tree canopy concealing aquatic habitats in the stream (tributary) and wetland classes.

On the 2013 aerial photograph, the remaining three habitat classes (ground, built, and sand/gravel) collectively comprise less than 10% of floodplain area. In descending order of importance, they were bare ground 5.6% (3,230 ac [1,307 ha]), built 3.6% (2,077 ac [841 ha]), and sand/gravel 0.5% (273 ac [110 ha]).

Table 3. Chehalis River Floodplain Area and River Distance Relationships. Floodplain boundary is based on the FEMA 100-year floodplain plus 100 m; segment boundaries are based on the georeferenced midline of the bounding tributaries from the 1938 aerial imagery. See text for details on imagery creation. Both English and metric units are provided to facilitate translation to various sources.

Segment		Area		Distance		Area/Distance	
#	Description	acres	hectares	River Miles (RM)	River Kilometers (RKm)	ac/RM	ha/RKm
1	Highway 101 Bridge to Wynoochee River	10,344	4,186	13.1	21.0	790	199
2	Wynoochee River to Satsop River	5,928	2,399	8.0	12.8	741	187
3	Satsop River to Porter Creek	8,347	3,378	14.2	22.8	588	148
4	Porter Creek to Black River	8,532	3,453	13.6	21.8	627	158
5	Black River to Scatter Creek	4,660	1,886	7.7	12.4	605	152
6	Scatter Creek to Skookumchuck River	6,831	2,764	12.7	20.4	538	136
7	Skookumchuck River to Newaukum River	3,852	1,559	9.1	14.6	423	107
8	Newaukum River to South Fork Chehalis River	5,393	2,182	14.4	23.1	375	94
9	South Fork Chehalis River to Elk Creek	2,320	939	12.8	20.6	181	46
10	Elk Creek to Potential Dam Location	1,118	452	8.5	13.7	132	33
	Totals	57,325	23,199	114.1	183.2	502	127

Table 4. Areas of Chehalis Floodplain Land Cover Classes by Segment. See Table 3 for Segment Descriptions.

Land Cover Class		Segment										Totals
Class Name	Units	1	2	3	4	5	6	7	8	9	10	
Built	ac	619	158	171	185	84	174	349	228	82	27	2,077
	ha	251	64	69	75	34	70	141	92	33	11	841
Ground	ac	294	608	403	385	186	336	471	422	88	37	3,230
	ha	119	246	163	156	75	136	191	171	36	15	1,307
Herbaceous	ac	947	2,735	4,237	3,338	1,377	3,064	1,889	2,533	866	257	21,243
	ha	383	1,107	1,715	1,351	557	1,240	764	1,025	350	104	8,597
Shrub/Small Tree	ac	3,723	809	1,353	1,669	661	993	426	895	414	200	11,143
	ha	1,507	327	548	675	267	402	172	362	168	81	4,509
Forested	ac	2,848	887	960	2,280	1,967	1,708	380	956	724	509	13,219
	ha	1,153	359	388	923	796	691	154	387	293	206	5,350
Main Channel	ac	1,117	325	269	273	144	285	146	152	96	61	2,868
	ha	452	132	109	110	58	115	59	62	39	25	1,161
Sand/Gravel	ac	17	28	27	61	49	25	3	26	19	18	273
	ha	7	11	11	25	20	10	1	11	8	7	110
Stream	ac	558	82	52	36	27	14	14	15	1	1	800
	ha	226	33	21	15	11	6	6	6	0	0	324
Wetland	ac	39	284	726	266	128	192	156	131	17	0	1,939
	ha	16	115	294	108	52	78	63	53	7	0	785
Man-made pond	ac	67	2	138	11	1	11	4	10	3	0	247
	ha	27	1	56	4	0	4	2	4	1	0	100
Indeterminate	ac	115	10	11	28	36	29	14	25	10	8	286
	ha	47	4	4	11	15	12	6	10	4	3	116
Overall Area	ac	10,344	5,928	8,347	8,532	4,660	6,831	3,852	5,393	2,320	1,118	57,325
	ha	4,186	2,399	3,378	3,453	1,886	2,764	1,559	2,182	939	452	23,199

Table 5. Percentage of Area in Land Cover Classes by Segment.

Habitat Class	Segment										Mean across Segments
	1	2	3	4	5	6	7	8	9	10	
Built	6.0	2.7	2.0	2.2	1.8	2.5	9.1	4.2	3.5	2.4	3.6
Ground	2.8	10.3	4.8	4.5	4.0	4.9	12.2	7.8	3.8	3.3	5.6
Herbaceous	9.2	46.1	50.8	39.1	29.5	44.9	49.0	47.0	37.3	23.0	37.1
Shrub/Small Tree	36.0	13.6	16.2	19.6	14.2	14.5	11.1	16.6	17.8	17.9	19.4
Forested	27.5	15.0	11.5	26.7	42.2	25.0	9.9	17.7	31.2	45.5	23.1
Main Channel	10.8	5.5	3.2	3.2	3.1	4.2	3.8	2.8	4.1	5.5	5.0
Sand/Gravel	0.2	0.5	0.3	0.7	1.1	0.4	0.1	0.5	0.8	1.6	0.5
Stream	5.4	1.4	0.6	0.4	0.6	0.2	0.4	0.3	0.0	0.1	1.4
Wetland	0.4	4.8	8.7	3.1	2.7	2.8	4.0	2.4	0.7	0.0	3.4
Man-made pond	0.6	0.0	1.7	0.1	0.0	0.2	0.1	0.2	0.1	0.0	0.4
Indeterminate	1.1	0.2	0.1	0.3	0.8	0.4	0.4	0.5	0.4	0.7	0.5
Totals	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Floodplain Land Cover Changes

Land cover changes were most evident in the three land cover categories we examined: agriculture (composite category), built (development), and forested. For the two periods over which all 10 floodplain segments can be compared (1938-1970s and 1970s-2013), agriculture and canopy (forested habitat) showed the greatest changes. In particular, the net rate of conversion to agricultural uses increased rapidly during the 1938-1970s interval, but then declined significantly during the 1970s-2013 interval (**Fig. 2**; see also **Table 6**). In contrast, net changes in canopy were its inverse over the same two time periods, the 1938-1970s net decline in conversion of canopy was greater in magnitude than the net increased land conversion to agriculture, and the 1970s-2013 net increase in the rate of addition of canopy was lesser in magnitude than the simultaneous decrease net loss in agricultural land. In marked contrast to agricultural and forested land, development showed a net increase in both time periods, but the increase in the more recent period was over double that of the earlier period (**Fig. 2**). Additional partitioning reveals a difference between the lower Chehalis floodplain (defined as below the Black River) and the upper Chehalis floodplain (above the Black River). In particular, the lower Chehalis floodplain shows a marked net decrease in forested land prior to the 1970s, but a net increase in forested land post-1970s; the upper Chehalis floodplain shows that pattern in reverse, though the magnitude of net change is less (**Fig. 3**). In particular, the upper Chehalis floodplain shows a modest net increase in forested land prior to the 1970s, whereas it shows a modest net decrease in forested land after the 1970s.

Figure 2. Net Land Use Change in the Chehalis Floodplain over 1938-1970s and 1970s-2013.

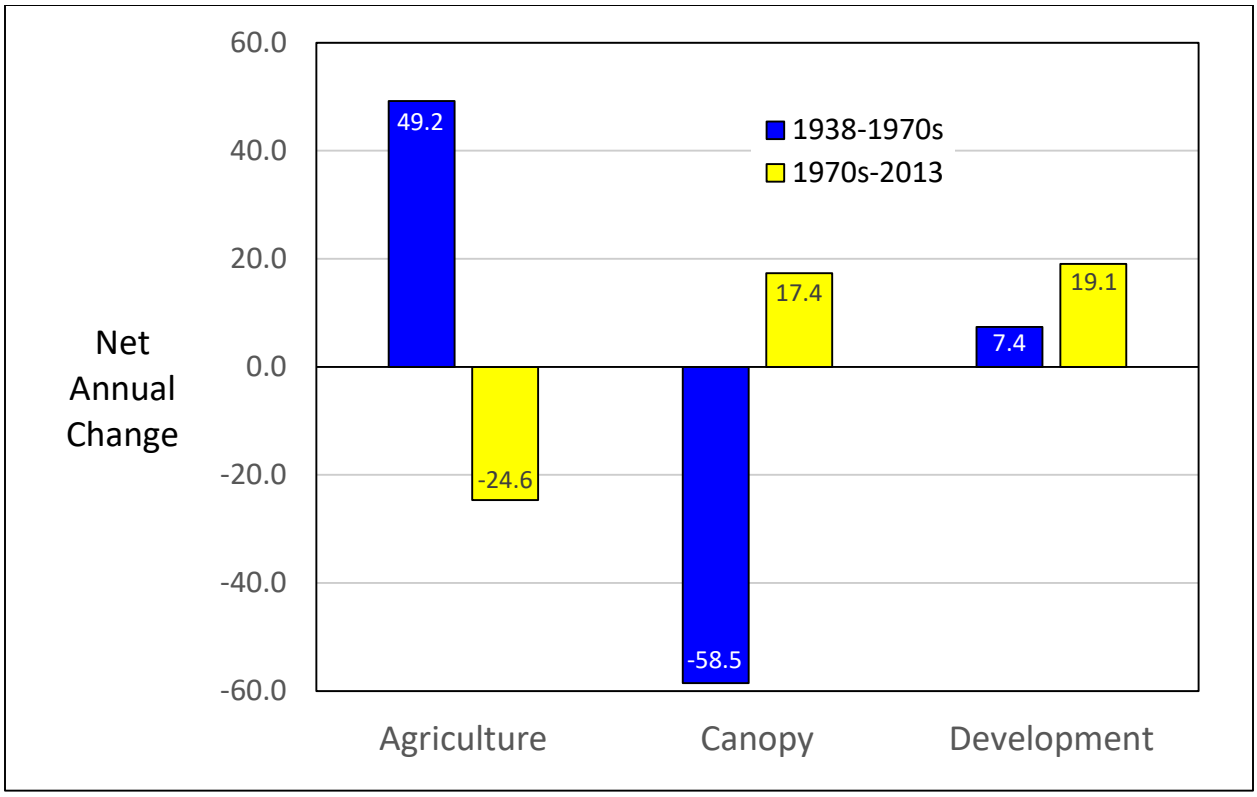
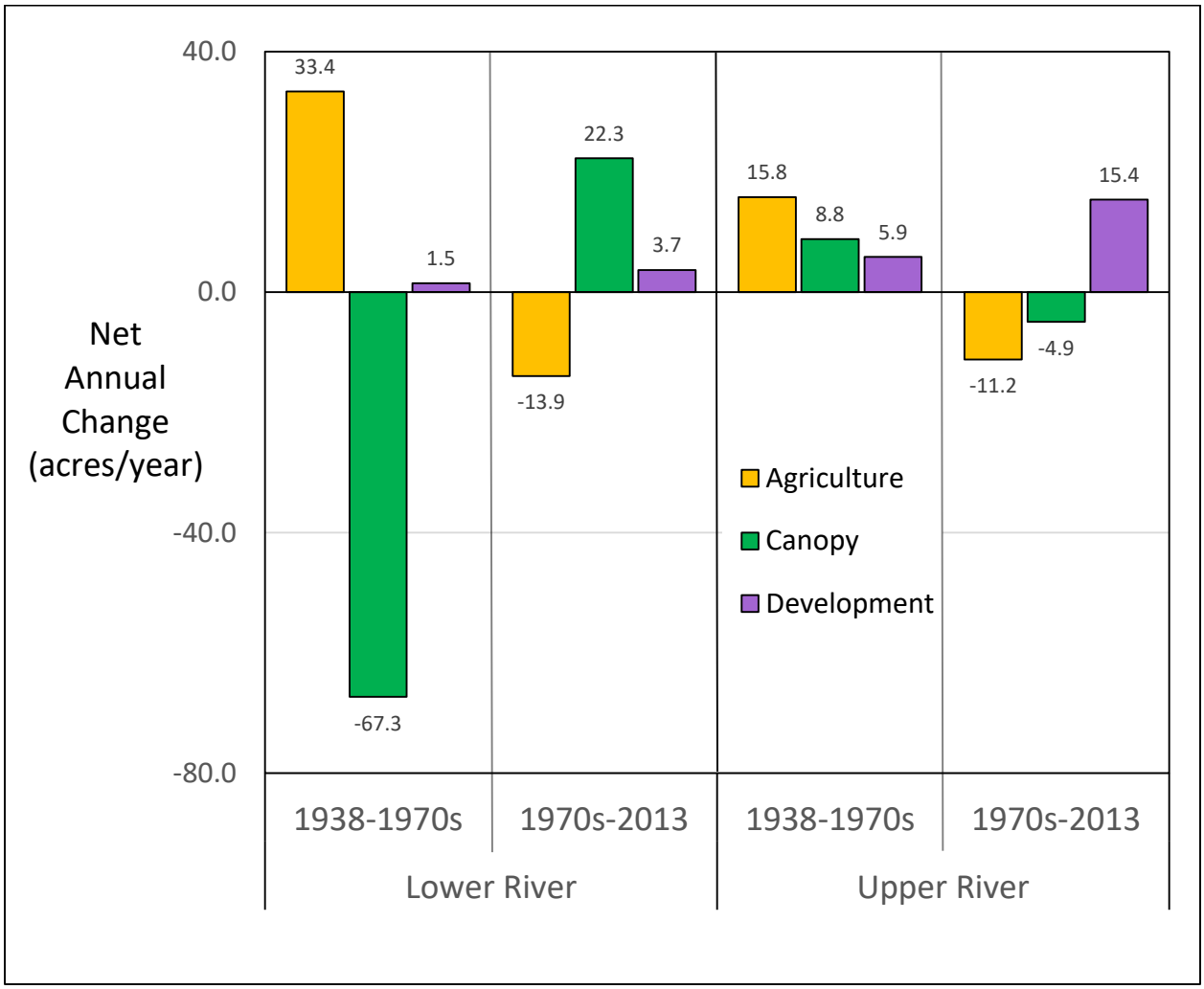


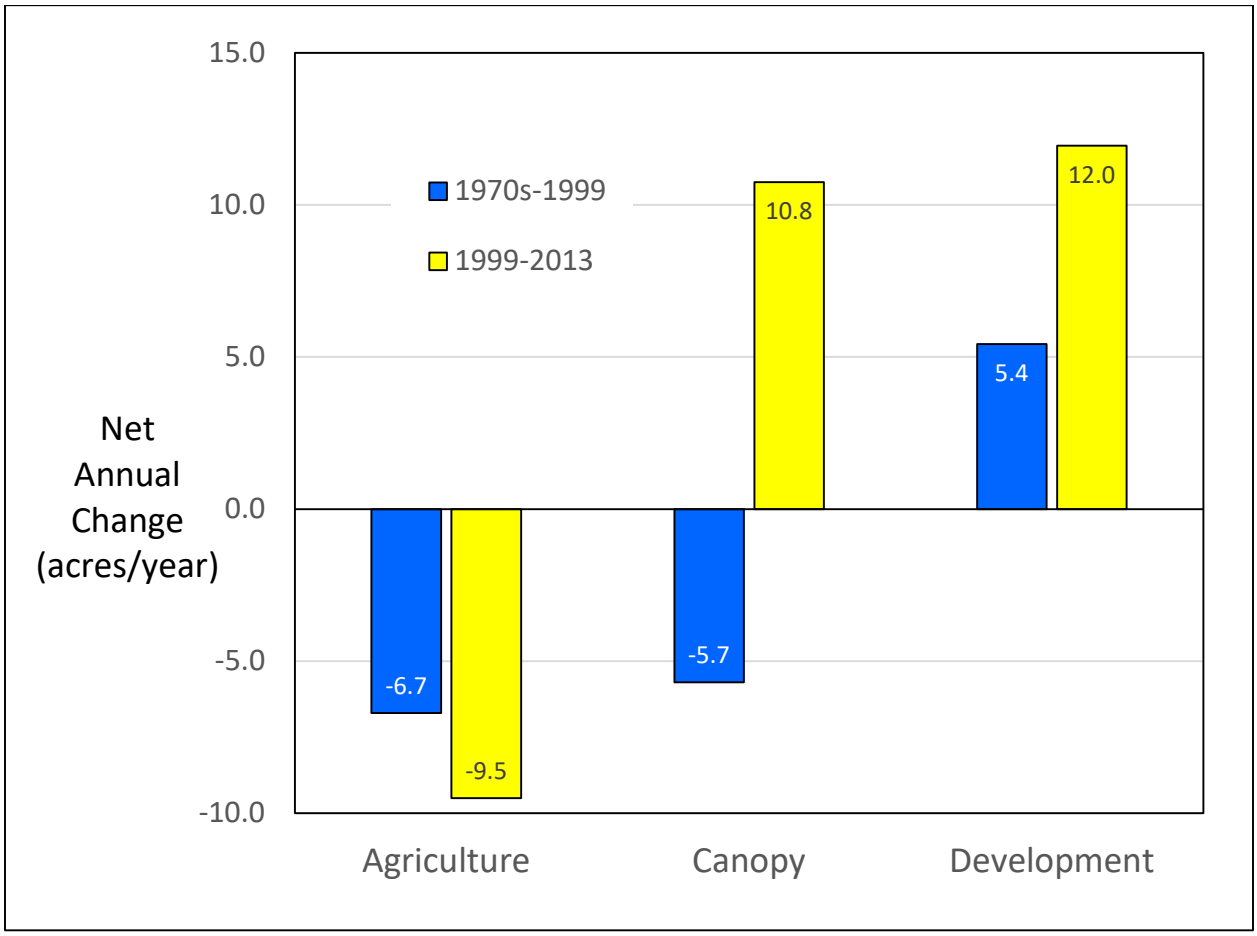
Figure 3. Net Land Use Changes in the Chehalis Floodplain over the Intervals 1938-1970 and 1970-2013 partitioned between the Lower and Upper Floodplain (the boundary defined as the Black River).



Comparing the eight segments above the Satsop River where 1999 aerial imagery is available provides more information. In particular, the increase in canopy observed in the 1970s-2013 interval (**Fig. 2**) appears to partly reflect a net decrease in canopy prior to 1999 versus a net increase afterwards (**Fig. 4**; see also **Table 6**). Moreover, the greater magnitude of the net increase in canopy in the 1970s-2013 interval (17.4 ac/yr; **Fig. 2**) than the magnitude of the net increase in canopy in the segments above the Satsop River in the 1999-2013 interval (10.8 ac/yr; **Fig. 4**) indicates that the two segments below the Satsop River, for which we lack data, had significant net increases in canopy. Second, the net rate of loss of agricultural land in the segments above the Satsop accelerated between the intervals before and after 1999 (**Fig. 4**). However, the rate of loss in those time intervals combined is less than the rate of loss over the same time period for all 10 segments, which indicates that the two missing data segments below Satsop River contributed significantly to that loss. Lastly, the net increase in development accelerated between the intervals

before and after 1999 (Fig. 4). However, the net increase in development for the entire 1970s-2013 interval period (17.4 ac/yr; **Fig. 4**) is only 1.7 ac/yr less that the net increase in development for all 10 segments over the same interval, indicating that the two segments below the Satsop River contributed relatively little to the overall net increase in development.

Figure 4. Net Land Use Changes in the Chehalis Floodplain above the Satsop River over the time intervals 1970s-1999 and 1999-2013.



Overall land cover changes in agriculture, canopy and development over the entire interval over which aerial imagery is available (1938-2013) shows three basic patterns:

1) A net increase in agriculture at the rate of 24.6 ac/yr;
2) A net decrease in canopy at the rate of -22.5 ac/yr; and
3) A net increase in development at the rate of 27.3 ac/yr.

Aerial coverage of aquatic habitats being less than that of terrestrial habitats made changes in those habitats more difficult to elucidate. Partitioning aquatic habitat into its two easily distinguishable categories (Chehalis Main channel, and Stream (tributaries) and Wetlands) over the seven segments with which we could make a comparison suggested an overall net increase in

Table 6. Net Annual Land Cover Change (acres/year) between Year Pairs – For the 1970s composite image, the year 1975 was used to calculate net annual changes. See text for details.

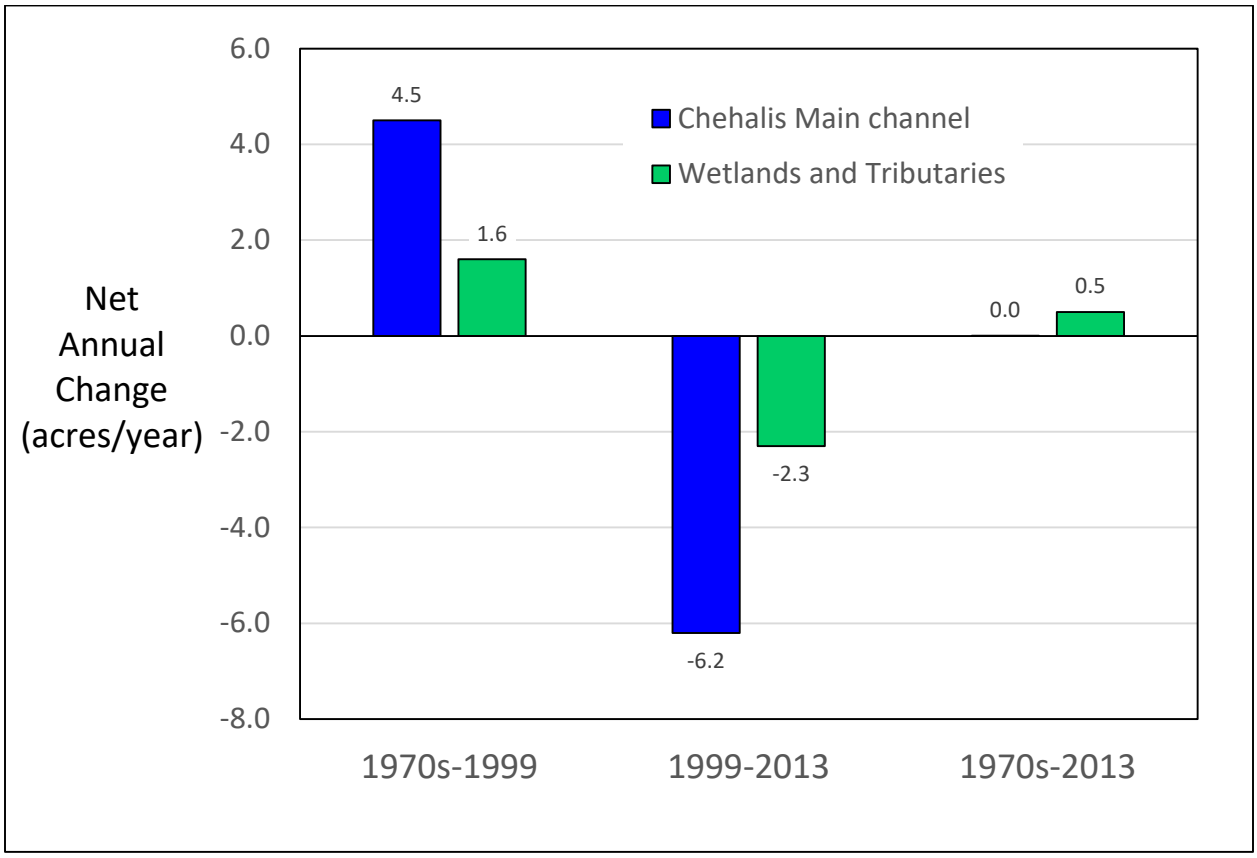
Segment	Category	1938-1970s	1970s-1999	1999-2013	1970s-2013	1938-2013
1	Agriculture (composite)	0.5	–	–	-0.7	-0.2
	Canopy (Forested)	-17.2	–	–	5.3	-11.9
	Chehalis Main channel	–	–	–	1.1	–
	Development (Built)	0.0	–	–	1.7	1.7
	Wetlands and Tributaries	–	–	–	1.3	–
2	Agriculture (composite)	6.6	–	–	-8.8	-2.2
	Canopy (Forested)	-9.8	–	–	5.9	-3.9
	Chehalis Main channel	–	–	–	0.6	–
	Development (Built)	1.1	–	–	0.4	1.5
	Wetlands and Tributaries	–	–	–	0.3	–
3	Agriculture (composite)	11.2	-2.6	–	-1.8	9.4
	Canopy (Forested)	-26.1	15.1	-13.3	3.5	-22.6
	Chehalis Main channel	–	–	–	0.0	–
	Development (Built)	0.5	-0.1	0.6	0.3	0.8
	Wetlands and Tributaries	–	–	–	-0.4	–
4	Agriculture (composite)	15.1	5.1	-7.7	-2.6	12.5
	Canopy (Forested)	-14.2	-10.5	18.1	7.6	-6.6
	Chehalis Main channel	–	-1.6	-1.9	-3.5	–
	Development (Built)	-0.1	0.4	0.0	0.4	0.3
	Wetlands and Tributaries	–	1.4	-2.6	-1.2	–
5	Agriculture (composite)	4.5	-1.2	0.0	-1.2	3.3
	Canopy (Forested)	0.3	0.3	0.3	0.6	0.9
	Chehalis Main channel	–	0.4	0.6	1.0	–
	Development (Built)	0.2	0.4	1.0	1.4	1.6
	Wetlands and Tributaries	–	-0.1	1.8	1.7	–
6	Agriculture (composite)	14.3	-1.5	-2.5	-4.0	10.3
	Canopy (Forested)	-1.1	-8.0	9.5	1.5	0.4
	Chehalis Main channel	–	2.7	-2.2	0.5	–
	Development (Built)	1.1	1.1	2.0	3.1	4.2
	Wetlands and Tributaries	–	0.0	-0.9	-0.9	–

Table 6 (continued). Net Annual Land Cover Change (acres/year) between Year Pairs – For the 1970s composite image, the year 1975 was used to calculate net annual changes. See text for details.

Segment	Category	1938-1970s	1970s-1999	1999-2013	1970s-2013	1938-2013
7	Agriculture (composite)	-10.1	-1.3	-0.2	-1.5	-11.6
	Canopy (Forested)	0.1	1.1	7.9	9.0	9.1
	Chehalis Main channel	–	1.0	-0.4	0.6	–
	Development (Built)	4.3	2.2	6.3	8.5	12.8
	Wetlands and Tributaries	–	-0.4	-0.3	-0.7	–
8	Agriculture (composite)	3.6	-4.8	1.2	-3.6	0.0
	Canopy (Forested)	2.8	-1.5	2.4	0.9	3.7
	Chehalis Main channel	–	0.8	-1.7	-0.9	–
	Development (Built)	0.4	1.2	1.4	2.6	3.0
	Wetlands and Tributaries	–	0.3	0.0	0.3	–
9	Agriculture (composite)	2.9	-0.5	0.0	-0.5	2.4
	Canopy (Forested)	5.1	0.3	-0.2	0.1	5.2
	Chehalis Main channel	–	0.8	-0.3	0.5	–
	Development (Built)	-0.1	0.3	0.7	1.0	0.9
	Wetlands and Tributaries	–	0.4	-0.4	0.0	–
10	Agriculture (composite)	0.6	0.1	0.0	0.1	0.7
	Canopy (Forested)	1.6	-3.3	4.9	1.6	3.2
	Chehalis Main channel	—	0.4	-0.3	0.1	—
	Development (Built)	0.0	0.3	0.2	0.5	0.5
	Wetlands and Tributaries	—	0.0	0.1	0.1	—
Overall	Agriculture (composite)	49.2	-6.7	-9.2	-24.6	24.6
	Canopy (Forested)	-58.5	-6.5	29.6	36.0	-22.5
	Chehalis Main channel	—	4.5	-6.2	0.0	—
	Development (Built)	7.4	5.8	12.2	19.9	27.3
	Wetlands and Tributaries	—	1.6	-2.3	0.5	—

the rate of change of both during the interval 1970s-1999, but a net decrease in the rate of change both during the interval 1999-2013 (**Fig. 6**). However, when one compares the entire time span that encompasses both those intervals, the net change in both categories almost vanishes. The water year 1998-1999, encompassing the period upon which the 1999 aerial was based, was the second wettest year on record for stations with long timelines (>80 years) in the Chehalis Basin, whereas the water years 1974-1975, 1977-1978, and 2012-2013, encompassing the year upon which the 1970s and 2013 aerials were based, were, respectively, dry, average, and wet years (see Appendix II).

Figure 6. Net Change in Chehalis Floodplain Aquatic Habitats over the intervals 1970s-1999 and 1999-2013.



Segment-Specific Land Cover Changes

Segment 1: Highway 101 Bridge to the Wynoochee River (**Appendix III** – pages 71-75) – This segment has the largest area among the 10 floodplain segments (10,344 ac [4,186 ha]. It ranks fourth in river length (13.1 RM [21.0 RKm]; **Table 3**), but has the greatest area of Chehalis Main channel among the 10 segments (1,117 ac [452 ha]), an area that comprises nearly double the Chehalis Main channel cover class in any other segment (**Table 4**; **Appendix III**, p. 73). It also has the greatest area of shrub/small tree cover (3,723 ac [1,507 ha]) and forest (2,848 ac [1,507 ha]) among the 10 segments]; **Table 4**), an area that comprises, respectively, over a third (36.1%)

and over one fifth (21.5%) that cover class across the 10 segments combined (**Table 5**). This segment also has the most substantial floodplain-based tributaries (as opposed to tributaries that enter from outside the floodplain), which is reflected having the greatest area in the stream (tributary) cover class among the 10 segments (558 ac [226 ha]; and except for the Wynoochee River along its upstream boundary, shows little evidence of channel migration over the entire interval over which aerial photographs were available (**Appendix III**, p. 73). Lastly, it has the greatest area in the built (developed) cover class (619 ac [251 ha]) of any of the 10 segments (**Table 5**).

Over 1938-2013, this segment sustained a small net loss in agricultural land (-0.2 ac/yr), most of which occurred after the 1970s (-0.7 ac/yr; **Table 6**). Among the four segments that have sustained a net loss in canopy, which are the four downstream-most floodplain segments, it sustained the second greatest loss over the time period 1938-2013 (-11.9 ac/yr), and most of that loss occurred prior to the 1970s (-17.2 ac/yr; **Table 6**). This segment has sustained a net positive gain in development over the 1938-2013 time period, all of which has occurred since the 1970s (**Table 6**).

Segment 2: Wynoochee River to the Satsop River (**Appendix III** – pages 76-80) – This segment ranks fifth in area among the 10 floodplain segments (5,928 ac [2,399 ha]), which partly reflects that it is the second to the shortest of the 10 segments in river length (8.0 mi [12.8 RKm]; **Table 3**) despite being downstream in the system where the floodplain is relatively broad (**Fig. 1**). The herbaceous cover class, which covers 2,735 ac (1,107 ha; **Table 4**), dominates this segment (46.1% of its area; **Table 5**). It ranks second in the Chehalis Main channel cover class area behind Segment 1, but its area of the main channel is less than one-third that of Segment 1 (325 ac [132 ha]) (**Table 4**). This segment shows more evidence of channel migration than any other segment; this is evident in the lower three-fifths of the Chehalis Main channel, and those portions of the Satsop and Wynoochee Rivers within the floodplain (**Appendix III**, p. 78).

Over 1938-2013, this segment sustained a net loss in agricultural land (-2.2 ac/yr), most of which occurred after the 1970s (-8.8 ac/yr; **Table 6**). Among the four segments that have sustained a net loss in canopy, which are the four downstream-most floodplain segments, it sustained the smallest loss over the time period 1938-2013 (-3.9 ac/yr), and most of that loss occurred prior to the 1970s (-9.8 ac/yr; **Table 6**). This segment showed a modest net positive gain in the rate development over 1938-2013, most of which occurred prior to the 1970s (**Table 6**).

Segment 3: Satsop River to Porter Creek (**Appendix III** – pages 81-85) – This segment ranks third in area (4,237 ac [1,715 ha]) and second in river length (14.2 mi [22.8 RKm]) among the 10 floodplain segments (**Table 3**). It ranks second in area of the Chehalis Main channel cover class behind Segment 1, however, that area is less than one-third of the area of Chehalis Main channel in Segment 1 (325 ac [132 ha]) (**Table 4**). Like Segment 2, the herbaceous cover class (8,347 ac [3,378 ha]) dominates this segment, and has a greater proportion of that cover class (50.8%) than in any of the remaining 10 segments (**Table 5**). This segment also has both the largest wetland area (726 ac [294 ha]); **Table 4**), an area that represents over a third of the wetland area (37.4%) across all 10 segments, and represents the largest percentage of wetlands the across the 10

segments as well (8.7%; **Table 5**). This segment also has the largest area of man-made ponds (138 ac [56 ha]; **Table 4**), an area that represents over half of the area (55.9%) of man-made ponds across the 10 segments. This segment generally has more limited evidence of channel migration in the Chehalis Main channel, though the portion of the Satsop River on the floodplain shows substantial migration (**Appendix III**, p. 83).

Over 1938-2013, this segment sustained a significant net gain in agricultural land (9.4 ac/yr), most of which occurred before the 1970s (11.2 ac/yr; **Table 6**). Among the four segments that have sustained a net loss in canopy, the four downstream-most floodplain segments, it sustained the greatest loss over the time period 1938-2013 (-22.6 ac/yr), and most of that loss occurred prior to the 1970s (-26.1 ac/yr; **Table 6**). This segment has sustained the second to the smallest net gain in development among the 10 segments over 1938-2013 (0.8 ac/yr; **Table 6**).

Segment 4: Porter Creek to Black River (**Appendix III** – pages 86-90) – This segment ranks second in area (8,532 ac [3,453 ha]) and fourth in river length (13.6 mi [21.8 RKm]; **Table 3**). The herbaceous and forested, and shrub/small tree cover classes dominate this segment, representing, collectively, 85.4% of its area (**Table 5**); all three cover classes rank second in their cover class over all 10 segments (**Table 4**). This segment shows evidence of channel migration downstream from the confluence with the Black River (**Appendix III**, p. 88).

Over 1938-2013, this segment sustained a significant net gain in agricultural land (12.5 ac/yr), most of which occurred before the 1970s (15.1 ac/yr; **Table 6**). Among the four segments that have sustained a net loss in canopy, which are the four downstream-most floodplain segments, it sustained the next to the smallest net loss over the time period 1938-2013 (-6.6 ac/yr), and most of that loss occurred prior to the 1970s (-14.2 ac/yr; **Table 6**). This segment has sustained the smallest net gain (0.6 ac/yr) in development across all 10 segments over 1938-2013 (**Table 6**). This segment also contained a large oxbow wetland in the 1999 that was part of the main stem in 1938 and the 1970s and again connected to the main stem in 2013. In 2013 it was digitized as part of the main stem due to the connection but could just as easily remained as off channel wetland. This sort of change may have implications for overall trends in main stem/wetland distributions and may suggest additional future analyses on these data.

Segment 5: Black River to Scatter Creek (**Appendix III** – pages 91-95) – This segment ranks seventh in area among the 10 floodplain segments (4,660 ac [1,886 ha]), and is the shortest segment in river length (7.7 mi [12.4 RKm]; **Table 3**). The forested (1,967 ac [796 ha]) and herbaceous (1,377 ac [557 ha]) cover classes dominate this segment (**Table 4**), representing, collectively, 71.8% of its area (**Table 5**). This segment shows some evidence of channel migration in the Chehalis Main channel at several points below the confluence of the Black River (**Appendix III**, p. 93).

Over 1938-2013, this segment sustained a small net gain in canopy (0.9 ac/yr), a slightly larger net gain in development (1.6 ac/yr) and an even larger net gain in agricultural land (3.3 ac/yr; **Table 6**). Most of net gain in agricultural land occurred before the 1970s, whereas most of the net gain in development occurred after the 1970s.

Segment 6: Scatter Creek to Skookumchuck River (**Appendix III** – pages 96-100) – This segment ranks fourth in area (6,381 ac [2,764 ha]) and sixth in river length (12.7 mi [20.4 RKm] among the 10 floodplain segments (**Table 3**). The herbaceous (3,064 ac [1,240 ha]) and forested (1,708 ac [691 ha]) and cover classes also dominate this segment (**Table 4**), representing, collectively, 69.9% of its area (**Table 5**). This segment shows limited evidence of channel migration somewhat downstream of Scatter Creek (**Appendix III**, p. 98).

Over 1938-2013, this segment sustained a significant net gain in agricultural land (10.3 ac/yr), most of which occurred before the 1970s (14.3 ac/yr; **Table 6**). This segment sustained a small net gain in canopy over 1938-2013 (0.4 ac/yr), which largely represents a tradeoff between losses prior to 1999 (-9.1 ac/yr) and gains post-1999 (9.5 ac/yr; **Table 6**). This segment has sustained a modest net positive gain in development over 1938-2013 (4.2 ac/yr), most of which occurred prior to the 1970s (3.1 ac/yr; **Table 6**).

Segment 7: Skookumchuck River to Newaukum River (**Appendix III** – pages 101-105) – This segment ranks eighth in area (3,852 ac [1,559 ha]) and seventh in river length (9.1 mi [14.6 RKm]) among the 10 floodplain segments (**Table 3**). The herbaceous cover class dominates this segment, covering almost half of its area (49.0%; **Table 5**). This segment has the second highest absolute area of development (built; 349 ac [141 ha]; **Table 4**), but that represents the highest proportion of development among the 10 segments (9.1%; **Table 5**), reflecting much of the urban area of Centralia and Chehalis. This segment shows the least evidence of channel migration of any segment over 1938-2013 (**Appendix III**, p. 103).

Over 1938-2013, this segment sustained a significant net loss in agricultural land (-11.6 ac/yr), most of which occurred before the 1970s (-10.1 ac/yr; **Table 6**). This segment sustained a net gain in canopy over the time period 1938-2013 (9.1 ac/yr), and most of that gain occurred since the 1970s (9.0 ac/yr; **Table 6**). This segment has sustained a significant net gain in development over 1938-2013 (12.8 ac/yr), most of which occurred since the 1970s (8.5 ac/yr; **Table 6**).

Segment 8: Newaukum River to South Fork Chehalis River (**Appendix III** – pages 106-110) – This segment ranks sixth in area (5,393 ac [2,182 ha]) but first in river length among the 10 floodplain segments (14.4 mi [23.1 RKm]; **Table 3**). The herbaceous cover class also dominates this segment, covering 47.0% of its area (**Table 5**). This segment shows substantial evidence of channel migration in the Chehalis Main channel up and downstream of its confluence with Bunker Creek (**Appendix III**, p. 108).

Over 1938-2013, this segment sustained no net change in agricultural land (0 ac/yr), but this reflects a net gain in agricultural land prior to the 1970s (3.6 ac/yr) countered by a equivalent net loss of agricultural land post-1970s (-3.6 ac/yr; **Table 6**). This segment sustained a net gain in canopy over the time period 1938-2013 (3.7 ac/yr), and most of that gain occurred the 1970s (2.8 ac/yr; **Table 6**). This segment has sustained a modest net gain in development over 1938-2013 (3.0 ac/yr), most of which occurred since the 1970s (2.6 ac/yr; **Table 6**).

Segment 9: South Fork Chehalis River to Elk Creek (**Appendix III** – pages 111-115) – This segment ranks ninth in area (2,320 ac [939 ha]) and fifth in river length (12.8 mi [20.6 RKm]) among the 10 floodplain segments (**Table 3**). The herbaceous and forested cover classes dominate

this segment, covering 68.5% of its area (**Tables 4** and **5**). This segment shows some evidence of channel migration in the Chehalis Main channel a few miles upstream of its confluence with the South Fork Chehalis River (**Appendix III**, p. 113).

Over 1938-2013, this segment sustained a small net gain in agricultural land (2.4 ac/yr), most of which occurred before the 1970s (2.9 ac/yr; **Table 6**). This segment sustained a modest net gain in canopy over the time period 1938-2013 (5.2 ac/yr), and most of that gain occurred prior to t1970s (5.1 ac/yr; **Table 6**). This segment has sustained a small net positive gain in development over 1938-2013 (0.9 ac/yr), most of which occurred post-1999 (0.7 ac/yr; **Table 6**).

Segment 10: Elk Creek to Potential Dam Location (**Appendix III** – pages 116-120) – This segment ranks last in area (1,118 ac [452 ha]) and eighth in river length (8.5 mi [13.7 RKm]) among the 10 floodplain segments (**Table 3**). The herbaceous and forested cover classes dominate this segment, covering 68.5% of its area (**Tables 4** and **5**). This segment shows very limited evidence of channel migration in the middle of the segment (**Appendix III**, p. 118).

Over 1938-2013, this segment sustained a small net gain in agricultural land (0.7 ac/yr), most of which occurred before the 1970s (0.6 ac/yr; **Table 6**). This segment sustained a modest net gain in canopy over the time period 1938-2013 (3.2 ac/yr), and most of that gain occurred since 1999 (4.9 ac/yr; **Table 6**). This segment has sustained a small net gain in development over 1938-2013 (0.5 ac/yr), which has occurred since the 1970s (0.5 ac/yr; **Table 6**).

Summary Conclusions and Next Steps

This habitat and change detection analysis of the Chehalis floodplain over the interval 1938-2013 led us to several basic conclusions:

1) Vegetation in various cover classes dominates the floodplain – nearly 80% of the landscape.
2) A significant proportion (~60%) of the vegetated landscape is agricultural lands.
3) Development is relatively restricted - <5% of the landscape.
4) More than half of the developed area is in Segments 1, 7 and 8.
5) Most of the net increase in agricultural lands occurred prior to the 1970s.
6) Most of the net decrease in forested lands occurred prior to the 1970s.
7) A net increase in development has occurred since the earliest aerials available (1938).
8) The post-1970s rate of net increase in development is over twice that of the pre-1970s rate.
9) Aquatic habitats occupy roughly 10% of the 2013 late summer landscape.
10) Roughly half of aquatic habitats are Chehalis River main channel.
11) Off-channel wetlands occupy roughly 3% of the 2013 late summer landscape.
12) Area of wetlands and tributaries is underestimated because concealment by vegetation.
13) The underestimate of wetland and tributary area is at least in the 20% range.
14) Aquatic habitat footprint changes more likely reflect year than functional differences.
15) Water visibility categories are useful to indicate levels of channel migration.
16) Channel migration occurs in a number of localized areas.
17) Channel migration is particularly prominent in portions of Segment 2.

18) Channel migration (within the 1938-2013 interval) is markedly deficient in Segment 7.

Future application of this kind of effort for high-level monitoring may be beneficial. However, one should consider the following if this is considered:

1) We have reasonable confidence in tracking terrestrial habitat categories, and availability of Lidar, IR, and other "bands" (all available since the 2013 NAIP aerial series) in addition to the standard RBG color bands will undoubtedly improve the quality of analysis if comparison to future dates are considered. However, more ground truthing will be required to partition vegetation categories into meaningful land cover types. However, the comprehensive digitizing of visible wet areas throughout the basin also gives us an excellent base on which to build a more comprehensive wetland layer and guide field work to rectify types of wetlands.
2) We are less confident in tracking aquatic habitat categories, but expect this may be possible if more ground truthing is done to better estimate vegetation concealment of aquatic habitats, and temporal standardization is done to minimize intra-seasonal variation. However, this kind of estimate will somehow also have to address inter-year variation. Selected approaches are available to determine the reality of vegetation concealment compromising aquatic habitat area estimation.
3) We were pleasantly surprised by the degree to which water visibility categories across years revealed channel migration patterns. Some kind of analysis could be conducted to quantify the degree to which migration occurs in target reaches. Coupling this with on-the-ground assessment of factors that affect channel migration (e.g., rip-rap, incision, etc.) may prove useful in better categorizing reaches for restoration.
4) The change process produced a large amount of data which likely could be mined for more insight. We did not specifically split the data into transition units through time to assess specific trajectories such as land that might have been forest in 1938, agriculture in the 1970s, and then development after or conversely return to forested. We also did not quantify the amount of wetland and main stem change that was due to boundary changes (shrink/swell) as opposed to new or filled locations; and have not quantified the amount of canopy loss due to river channel migration or reforestation on old channel beds. These analyses, as needed, would all facilitated by the data generated in this project.

Literature Cited

Pierce KB Jr. 2015. Accuracy optimization for high resolution object-based change detection: An example mapping regional urbanization with 1-m aerial imagery. *Remote Sensing* 7(10):12654-12679.

Turner BL II, Lambin EF, Reenberg A. 2007. The emergence of land change science for global environmental change and sustainability. *Proceeding of the National Academy of Sciences, USA* 104(52):20666–20671.

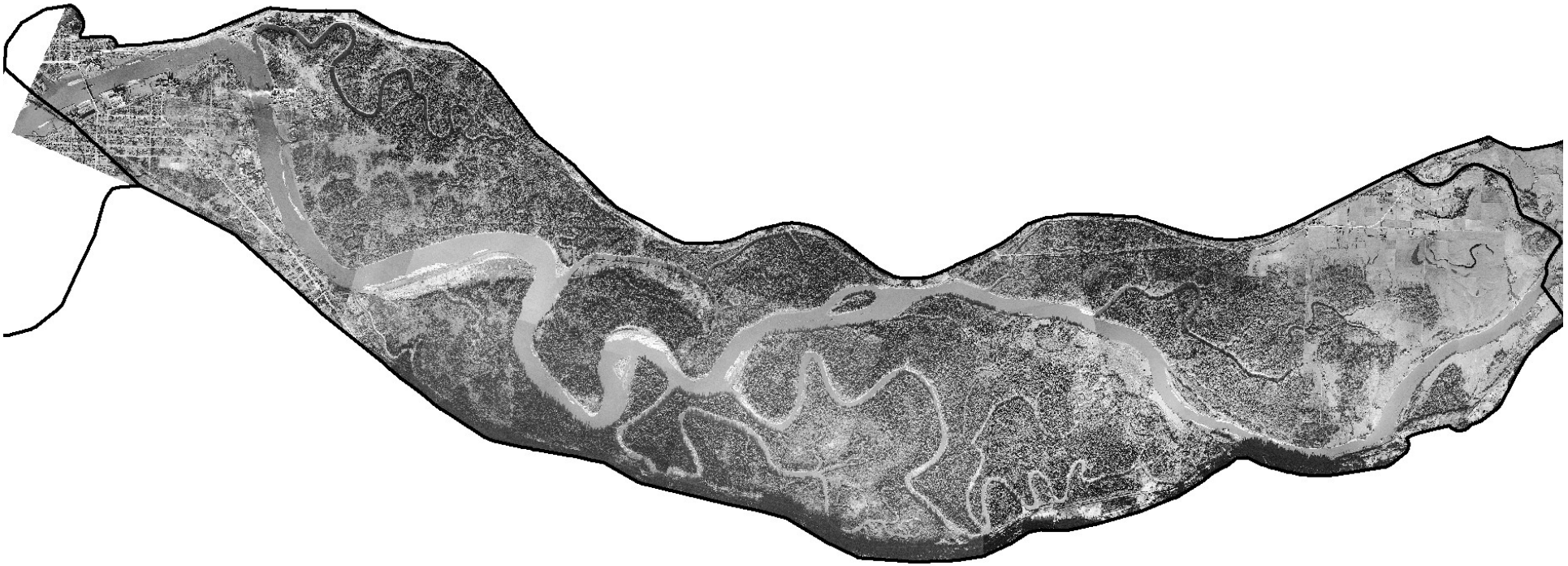
Appendix 1. Chehalis River Segment Aerial Photographs

This appendix shows the aerial photographic plates of the Chehalis River segments upon which change analyses were based. Four panels, one each for year of the time series (1938, 1970s [1975 and 1978 composite]), 1999, and 2013) for each segment are presented. For each segment, the lateral boundaries are the FEMA 100-year floodplain plus 100 meters, and the terminal boundaries are the midline of the channel of the bounding tributaries based on the 1938 orthorectified aerial photograph. Plates for some years in some segments are missing aerial coverage, these shown as blank areas within segment boundaries. Areas of missing aerial coverage by year for each segment are listed in the following table. The year 2013 is not listed because no segments were missing aerial coverage in that year.

Segment				Area of Missing Coverage								
#	Description	Area		1938			1970s			1999		
		ac	ha	ac	ha	%	ac	ha	%	ac	ha	%
1	Highway 101 Bridge to Wynoochee River	10,344	4,186	70	28	0.68	0	0	0	10,344	4,186	100.00
2	Wynoochee River to Satsop River	5,928	2,399	632	256	10.66	0	0	0	5,928	2,399	100.00
3	Satsop River to Porter Creek	8,347	3,378	366	148	4.38	0	0	0	1,274	516	15.26
4	Porter Creek to Black River	8,532	3,453	463	187	5.43	0	0	0	0	0	0
5	Black River to Scatter Creek	4,660	1,886	94	38	2.02	39	16	0.84	0	0	0
6	Scatter Creek to Skookumchuck River	6,831	2,764	729	295	10.67	0	0	0	105	42	1.54
7	Skookumchuck River to Newaukum River	3,852	1,559	309	125	8.02	0	0	0	0	0	0
8	Newaukum River to South Fork Chehalis River	5,393	2,182	433	175	8.03	0	0	0	0	0	0
9	South Fork Chehalis River to Elk Creek	2,320	939	51	21	2.20	0	0	0	0	0	0
10	Elk Creek to Proposed Dam Location	1,118	452	777	314	69.50	0	0	0	0	0	0
	Totals	57,325	23,199	3,924.0	183.2	6.85	39.0	15.8	0.07	17,651	7,143	30.79

Segment 1: Highway 101 Bridge to Wynoochee River

1938 Aerial Photograph

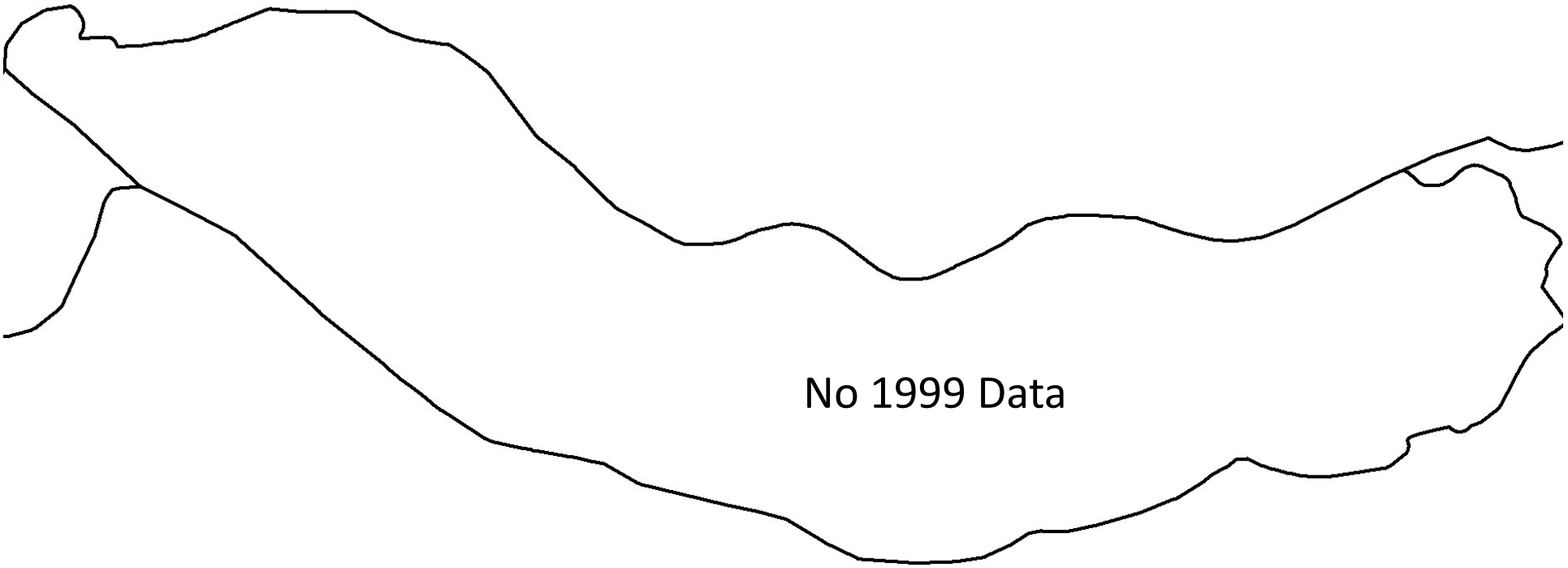


Segment 1: Highway 101 Bridge to Wynoochee River

1975/1978 Composite Aerial Photograph

Segment 1: Highway 101 Bridge to Wynoochee River

1999 Aerial Photograph

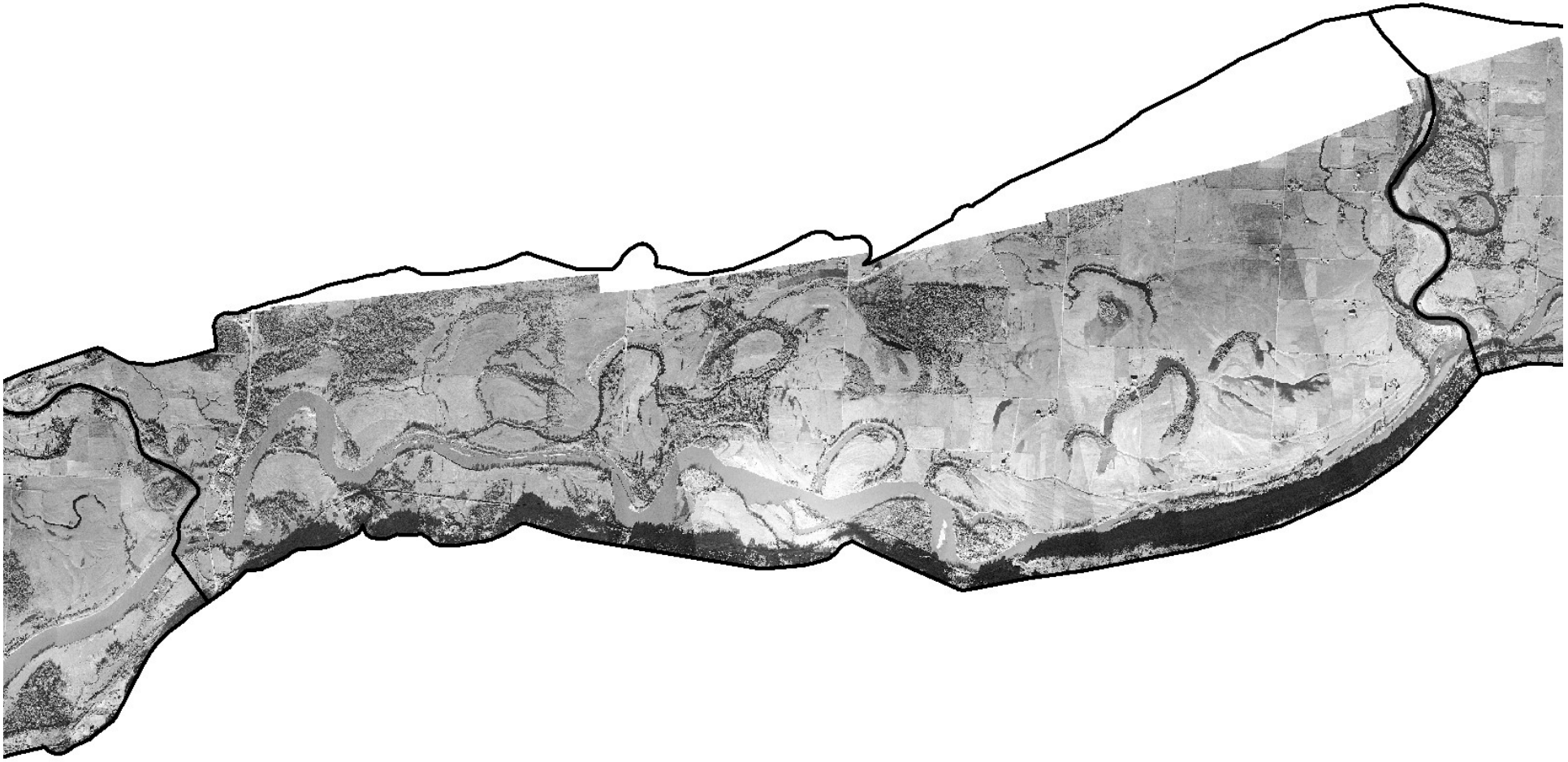


Segment 1: Highway 101 Bridge to Wynoochee River

2013 Aerial Photograph

Segment 2: Wynoochee River to Satsop River

1938 Aerial Photograph



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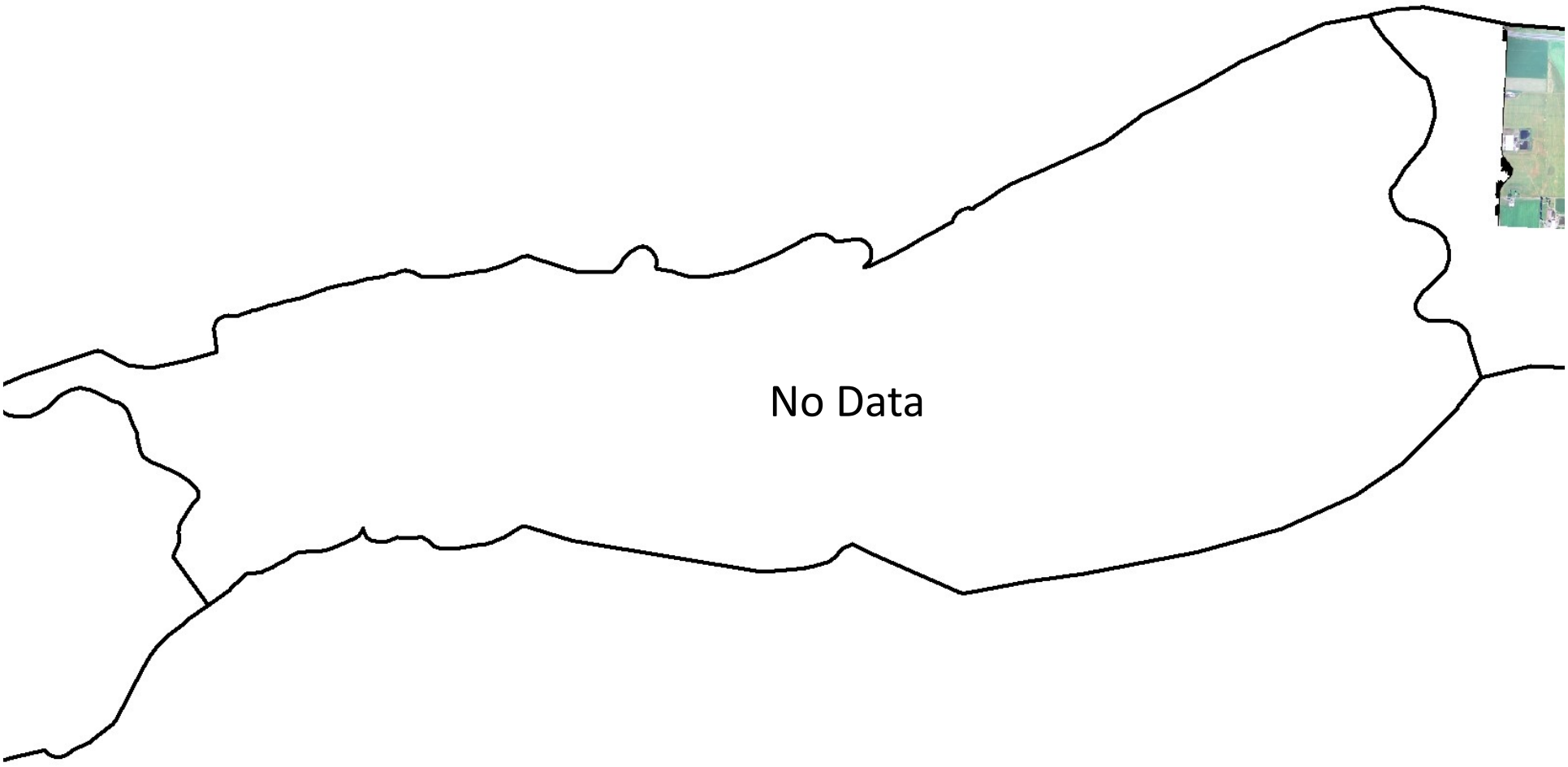
1975/1978 Composite Aerial Photograph

Segment 2: Wynoochee River to Satsop River

1999 Aerial Photograph



Segment 2: Wynoochee River to Satsop River

2013 Aerial Photograph

Segment 3: Satsop River to Porter Creek

1938 Aerial Photograph

Segment 3: Satsop River to Porter Creek

1975/1978 Composite Aerial Photograph

Segment 3: Satsop River to Porter Creek

1999 Aerial Photograph

Segment 3: Satsop River to Porter Creek

2013 Aerial Photograph

Segment 4: Porter Creek to Black River

1938 Aerial Photograph

Segment 4: Porter Creek to Black River

1975/1978 Composite Aerial Photograph

Segment 4: Porter Creek to Black River

1999 Aerial Photograph

Segment 4: Porter Creek to Black River

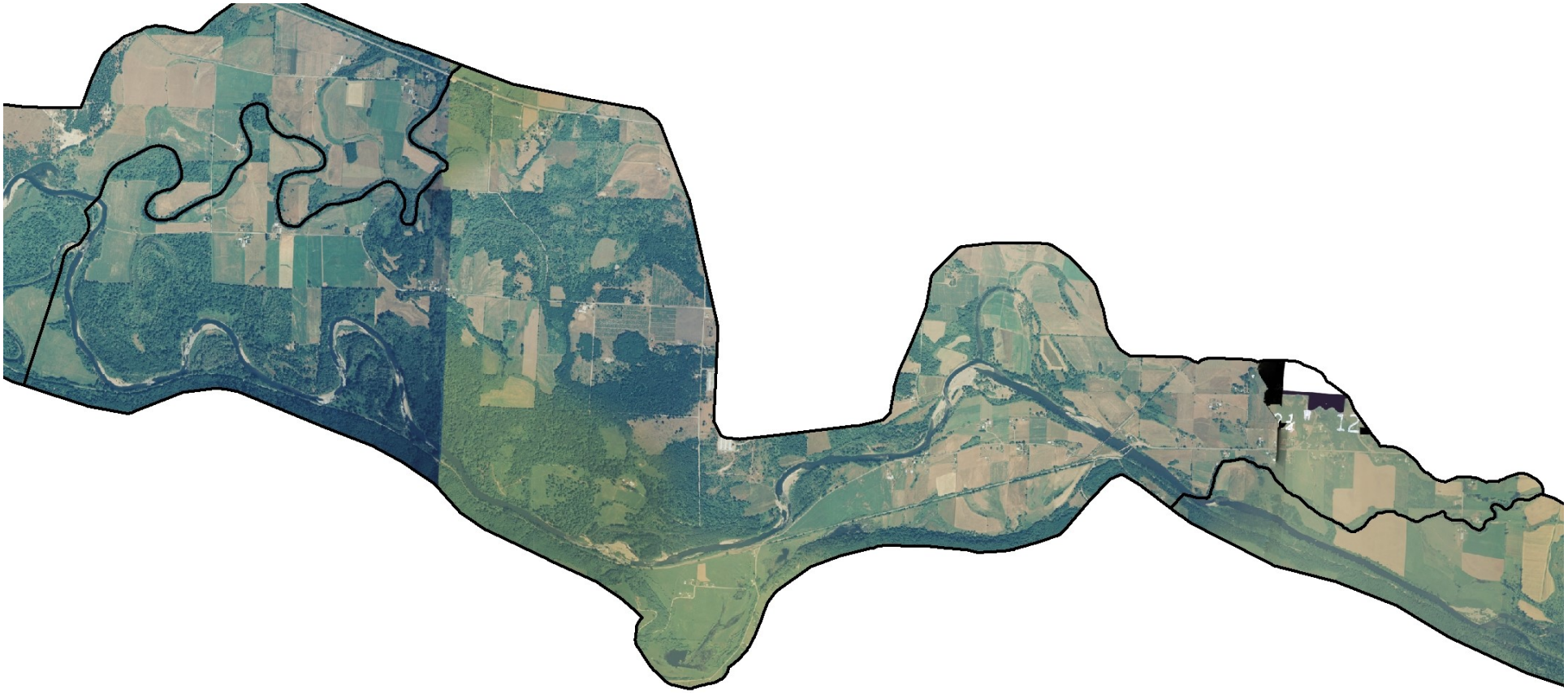
2013 Aerial Photograph

Segment 5: Black River to Scatter Creek

1938 Aerial Photograph

Segment 5: Black River to Scatter Creek

1975/1978 Composite Aerial Photograph

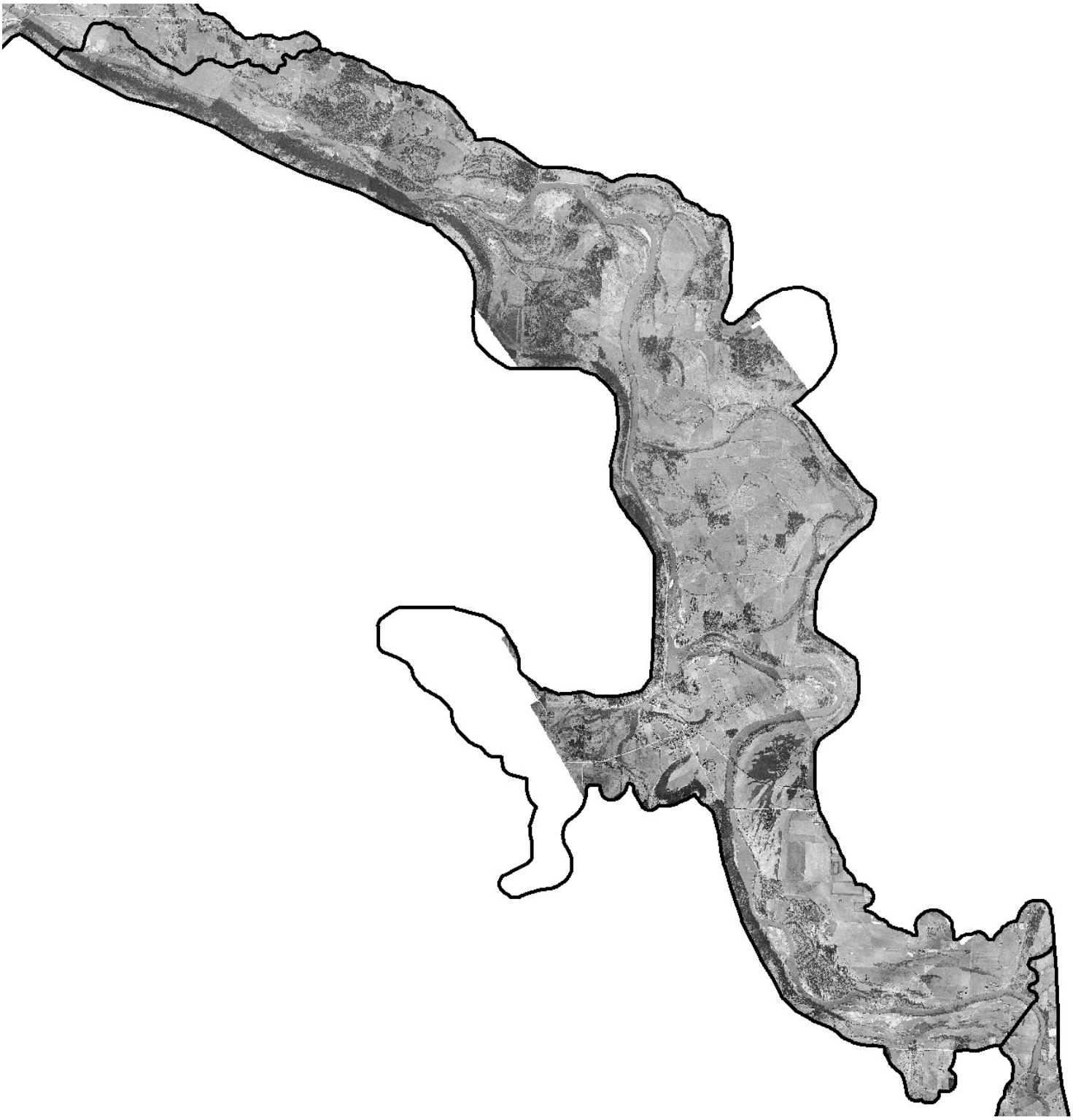


Segment 5: Black River to Scatter Creek

1999 Aerial Photograph

Segment 5: Black River to Scatter Creek

2013 Aerial Photograph



1938 Aerial Photograph

Segment 6: Scatter Creek to Skookumchuck River

1975/1978 Composite Aerial Photograph

Segment 6: Scatter Creek to Skookumchuck River

1999 Aerial Photograph

Segment 6: Scatter Creek to Skookumchuck River

2013 Aerial Photograph

Segment 6: Scatter Creek to Skookumchuck River

Segment 7: Skookumchuck River to Newaukum River

1938 Aerial Photograph

Segment 7: Skookumchuck River to Newaukum River

1975/1978 Composite Aerial Photograph

Segment 7: Skookumchuck River to Newaukum River

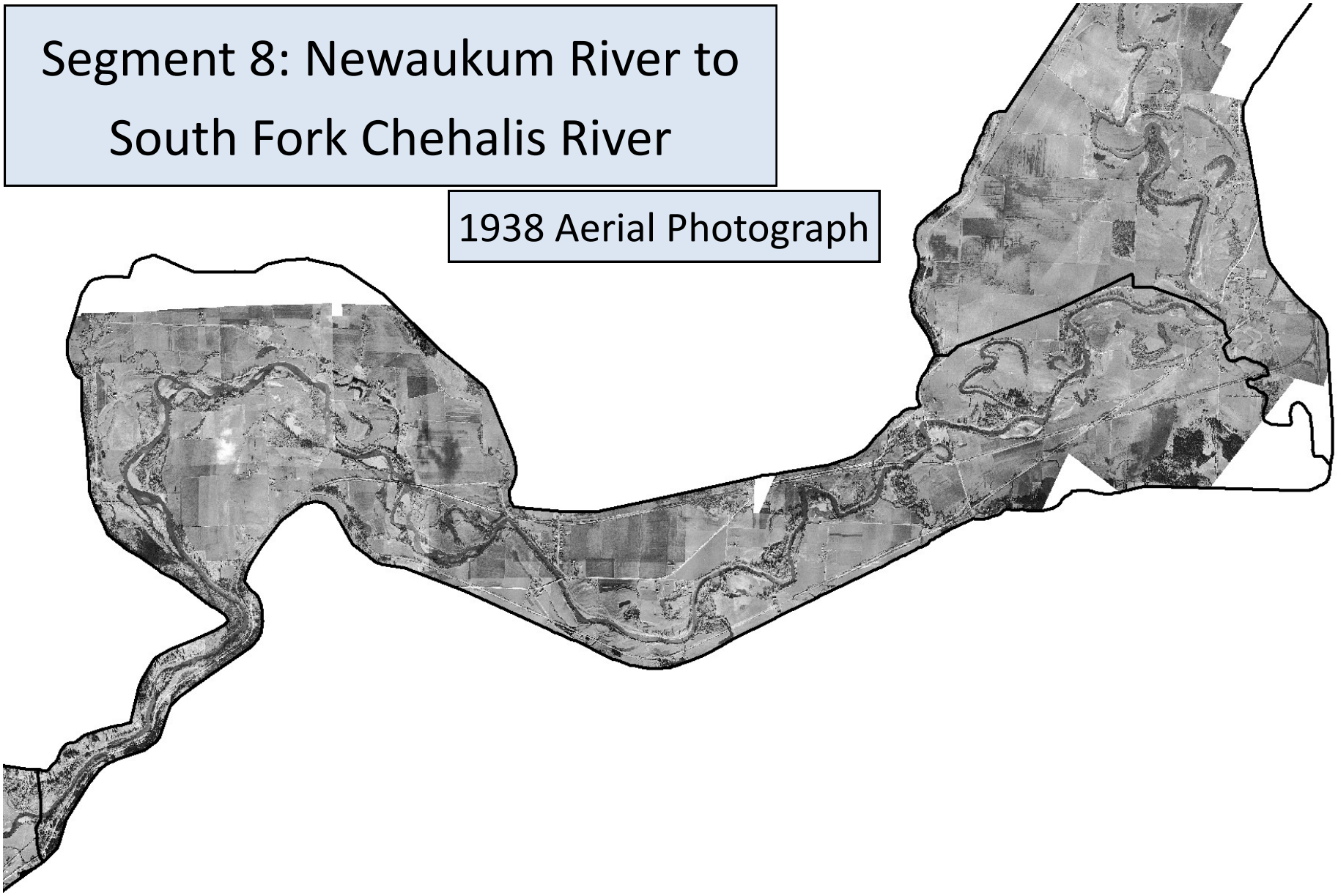
1999 Aerial Photograph

Segment 7: Skookumchuck River to Newaukum River

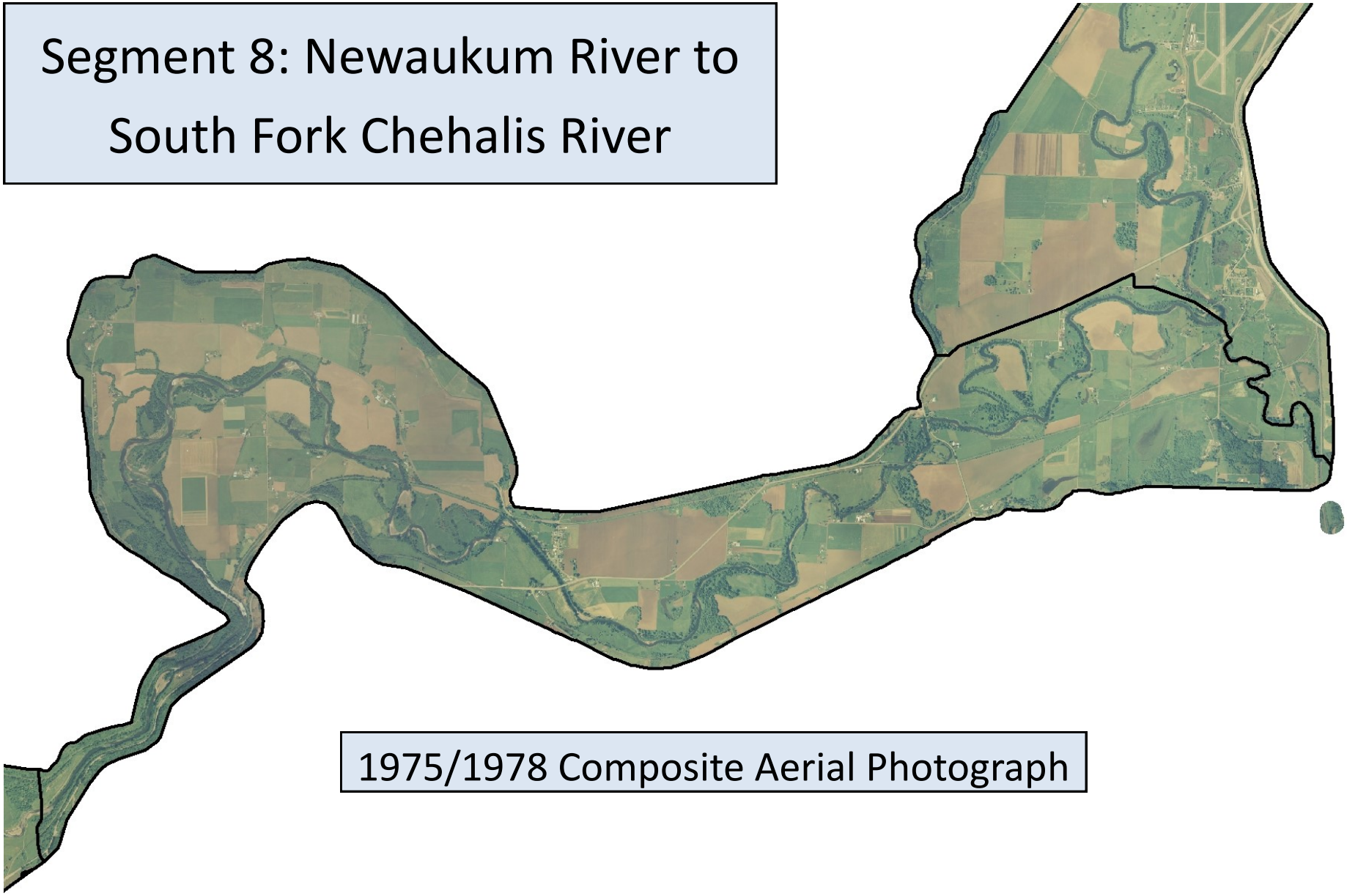
2013 Aerial Photograph

Segment 8: Newaukum River to South Fork Chehalis River

1938 Aerial Photograph



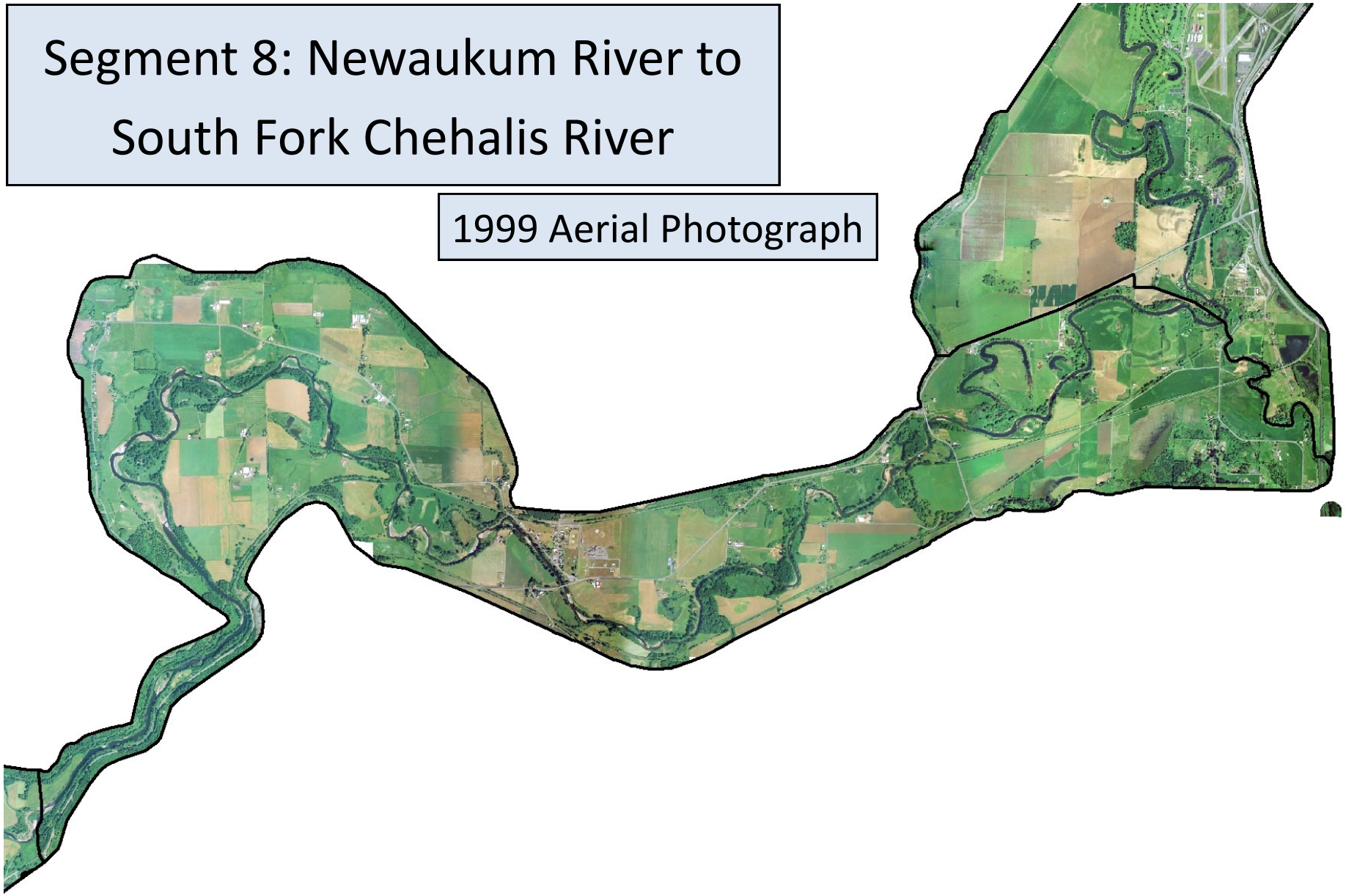
Segment 8: Newaukum River to South Fork Chehalis River



1975/1978 Composite Aerial Photograph

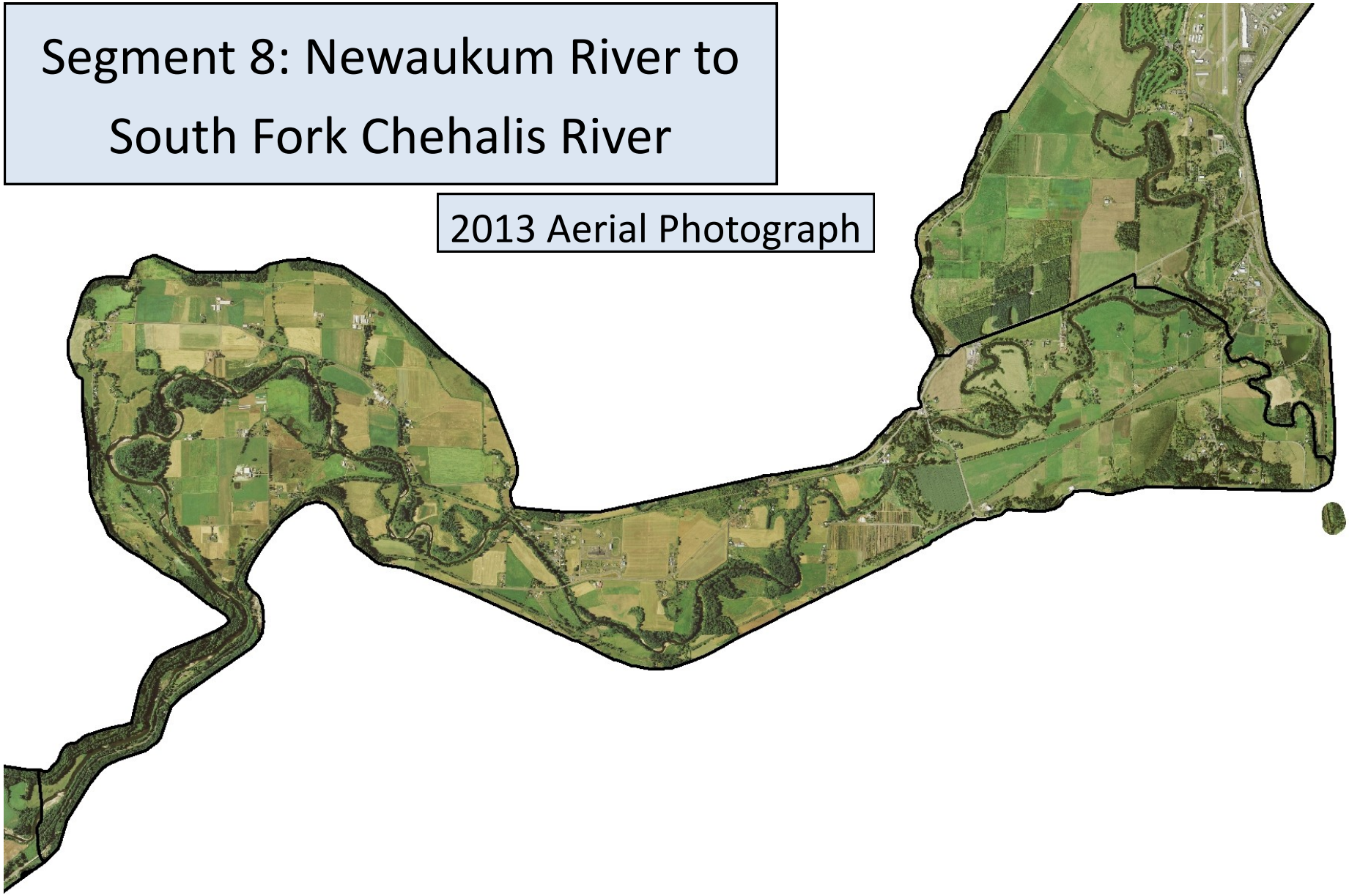
Segment 8: Newaukum River to South Fork Chehalis River

1999 Aerial Photograph



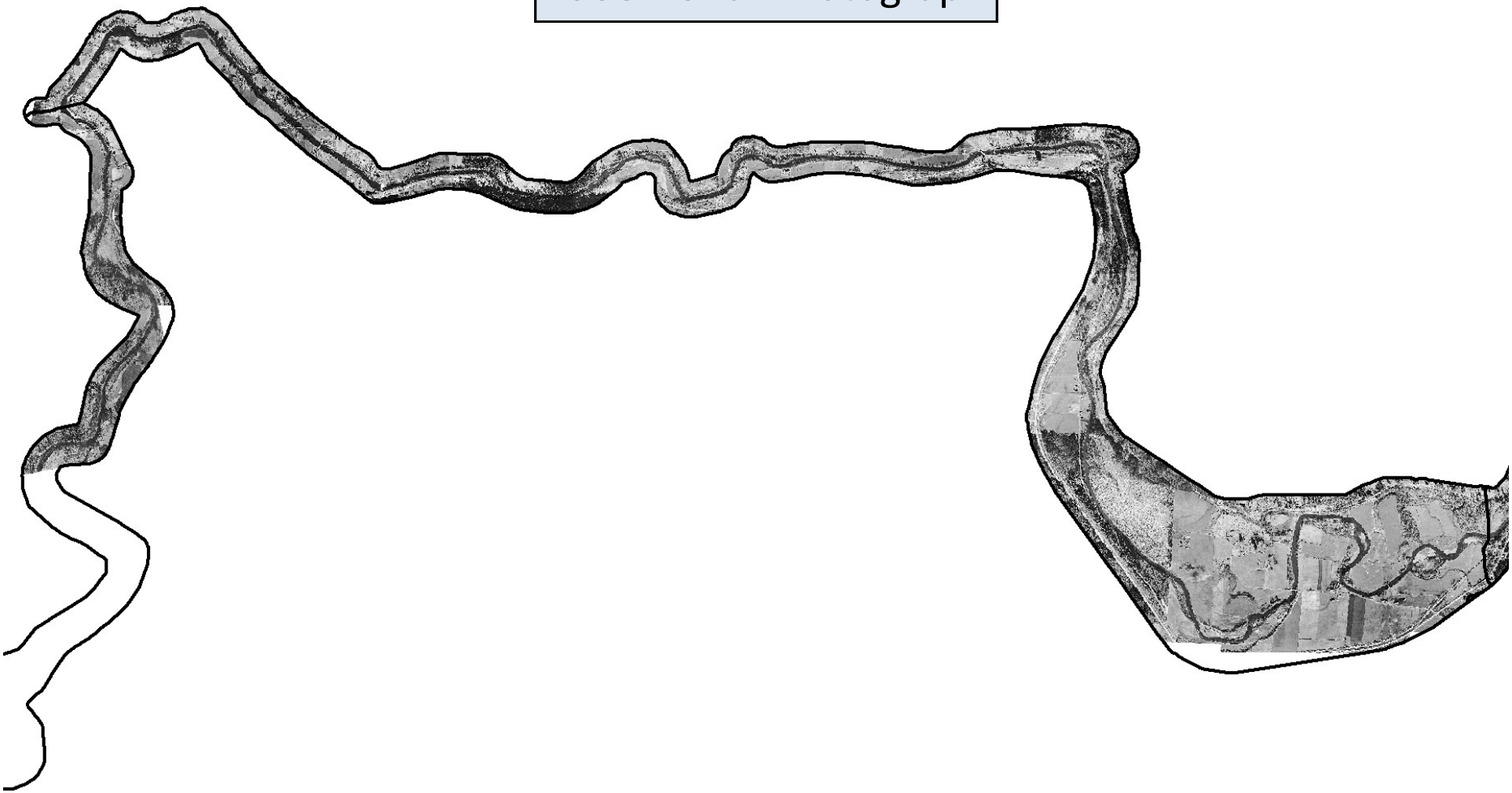
Segment 8: Newaukum River to South Fork Chehalis River

2013 Aerial Photograph



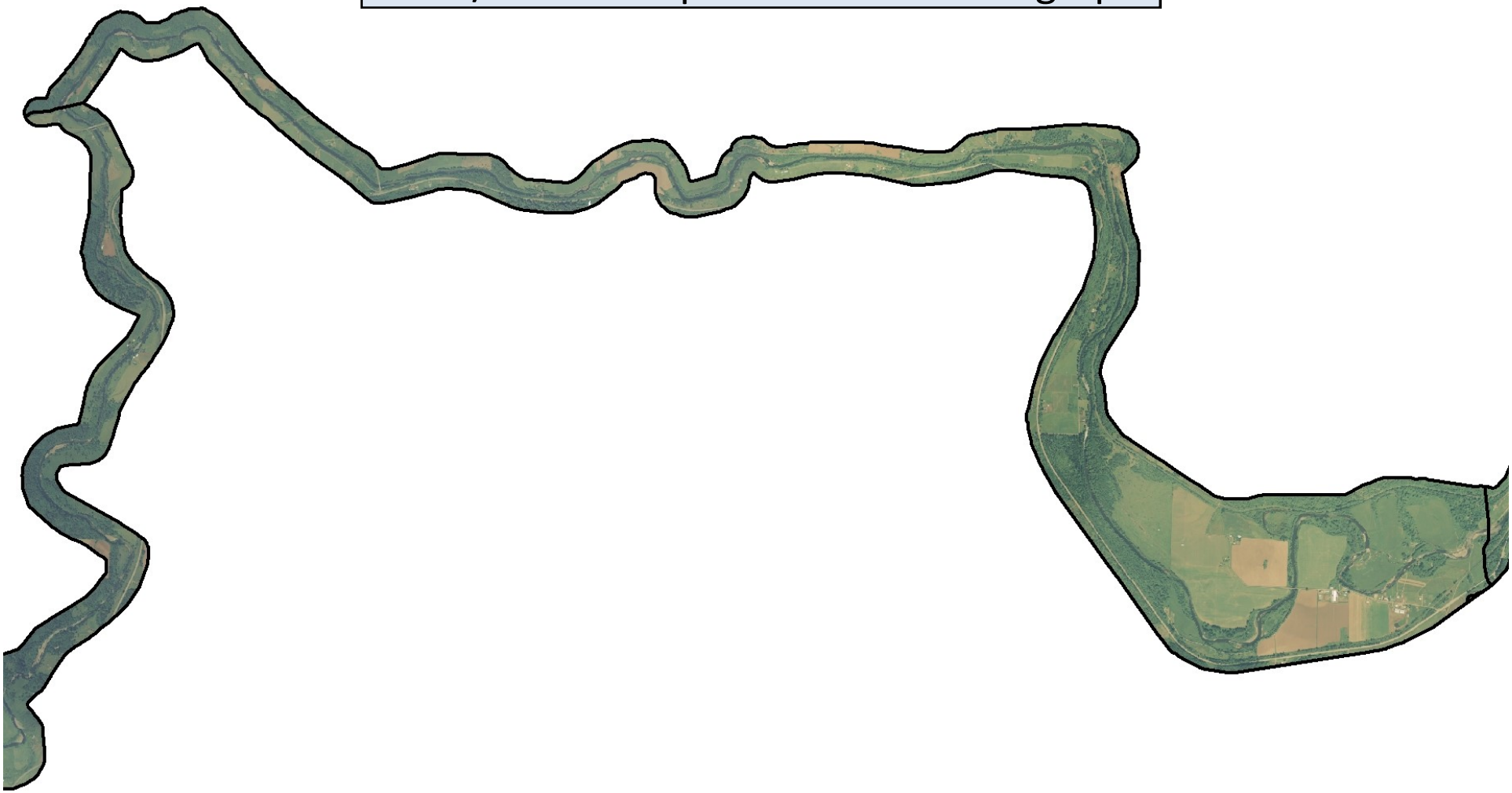
Segment 9: South Fork Chehalis River to Elk Creek

1938 Aerial Photograph



Segment 9: South Fork Chehalis River to Elk Creek

1975/1978 Composite Aerial Photograph

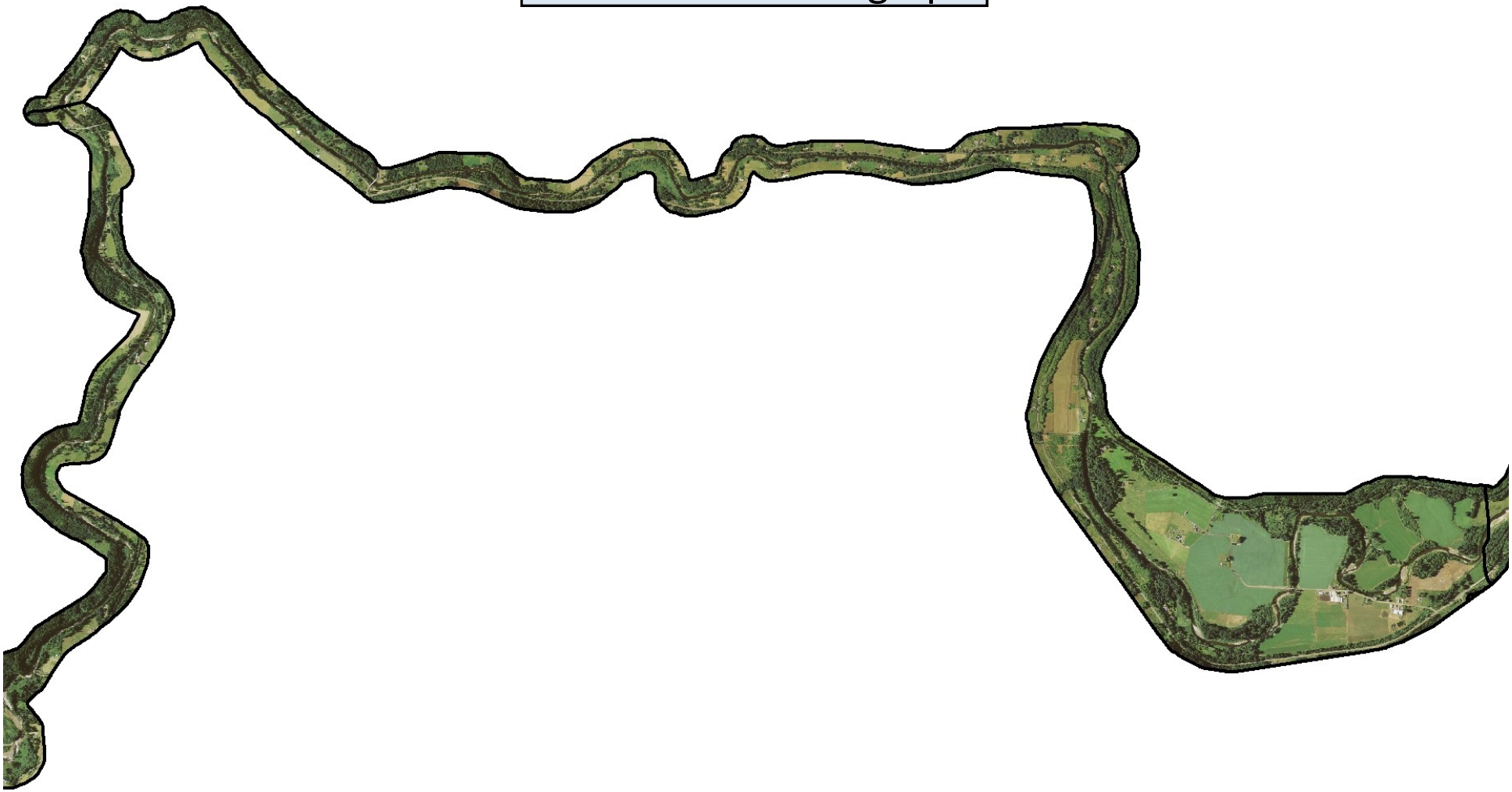


Segment 9: South Fork Chehalis River to Elk Creek

1999 Aerial Photograph

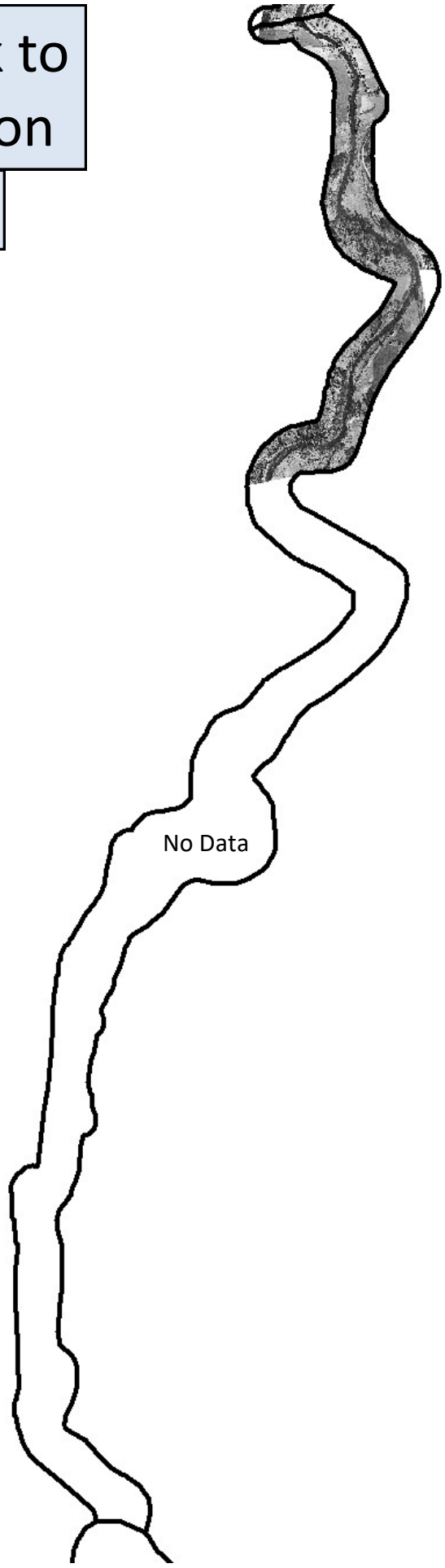
Segment 9: South Fork Chehalis River to Elk Creek

2013 Aerial Photograph



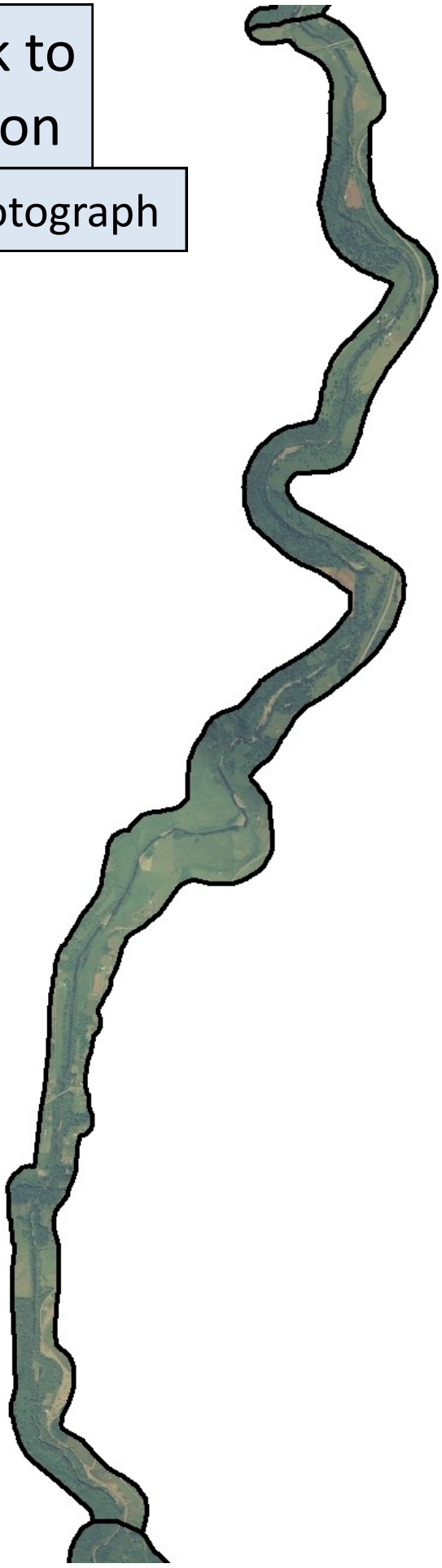
Segment 10: Elk Creek to Proposed Dam Location

1938 Aerial Photograph



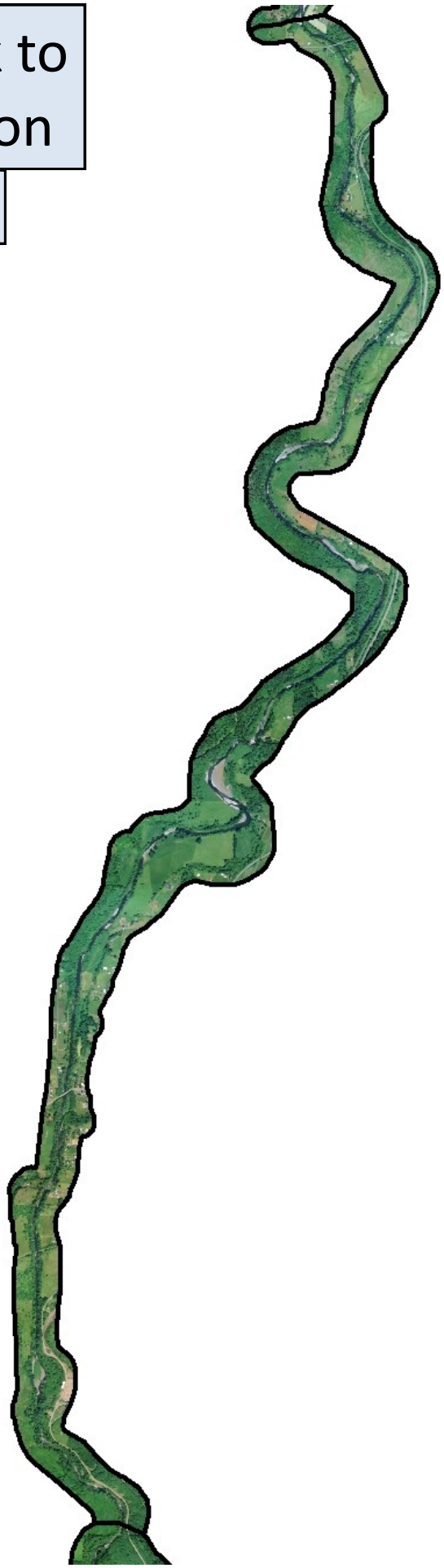
Segment 10: Elk Creek to Proposed Dam Location

1975/1978 Composite Aerial Photograph



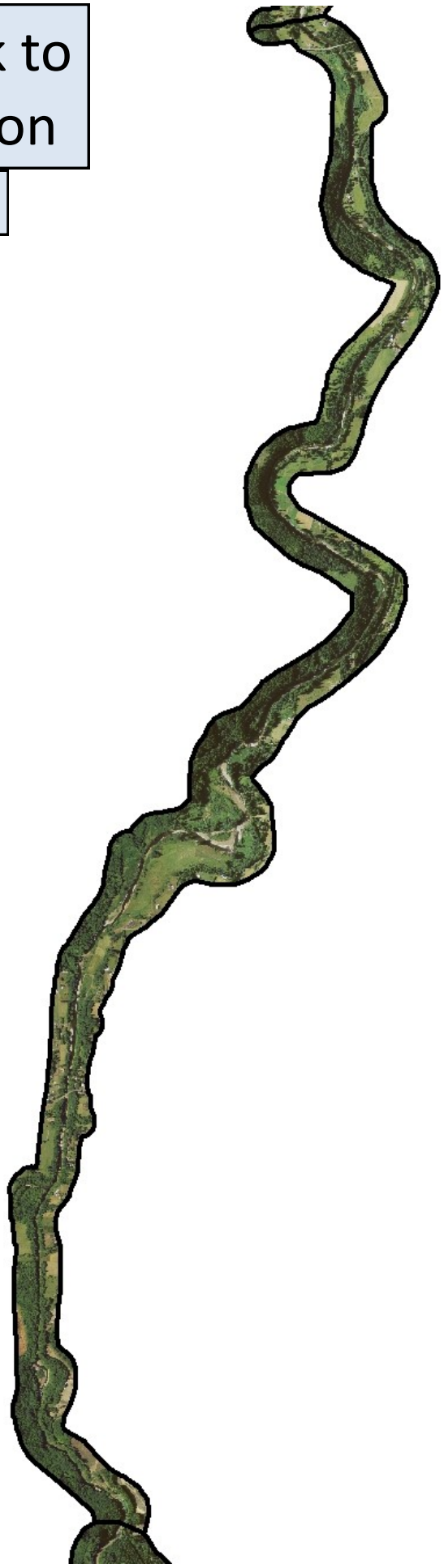
Segment 10: Elk Creek to Proposed Dam Location

1999 Aerial Photograph



Segment 10: Elk Creek to Proposed Dam Location

2013 Aerial Photograph



Appendix II. Degree of Wetness among Water Years based on Precipitation

We evaluated degree of wetness among water years based on precipitation. We use the 112 years for the Station at Aberdeen from water years 1904-1905 to 2015-2016. We excluded 18 years with incomplete data (missing months). To create intervals for year classes with varying degrees of wetness, we first obtained the mean and standard deviation of water year precipitation for the 94 year dataset. We then centered the "Average" water year on the mean with a width of one standard deviation; "Dry" and "Wet" years encompassed one standard deviation, respectively, below and above the "Average" water year band; "Very Dry" and "Very Wet" years encompassed one standard deviation, respectively, below and above the "Dry" and "Wet" bands. As the distribution of water years was asymmetric (had a longer wet tail), we added an "Extremely Wet" class, which encompassed one standard deviation above the "Very Wet" band. The interval limits for these categories are indicated and color-coded below. All data are in inches. We then coded all years in the dataset into these classes (see Appendix Table I). Additionally, years with the yellow highlighted year line across all columns except the total precipitation column are those that include the time interval for which we analyzed aerial photographs.

	Interval Limits	
	Lower	Upper
Very Dry	48.2	61.9
Dry	62.0	75.7
Average	75.8	89.5
Wet	89.6	103.3
Very Wet	103.4	117.1
Extremely Wet	117.2	130.86

Appendix Table I. Water Years used in Degree of Wetness Analysis.

Ctr	Water Year		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total Precipitation (inches)
1	1904	1905	3.9	15.8	11.9	12.2	6.0	11.9	1.9	4.5	4.4	0.5	1.7	7.6	82.34
2	1905	1906	11.6	7.1	14.7	12.3	8.5	5.2	2.9	3.8	5.1	0.0	0.6	8.3	80.01
3	1906	1907	11.0	15.9	11.2	11.4	9.1	7.1	5.6	2.7	1.6	0.4	0.7	3.0	79.75
4	1907	1908	2.3	13.3	17.5	11.0	9.0	15.3	7.6	5.0	1.8	0.1	2.6	0.3	85.75
5	1908	1909	5.5	11.1	10.7	14.1	14.8	7.3	2.1	4.2	2.3	2.5	1.3	1.5	77.26
7	1910	1911	10.1	15.3	12.2	11.2	4.9	4.0	4.4	8.1	1.4	0.8	0.8	4.0	77.20
11	1914	1915	9.8	13.4	4.4	9.0	6.3	6.3	4.7	6.5	0.6	2.0	0.4	1.6	64.99
12	1915	1916	9.2	11.9	17.3	9.2	13.8	19.6	4.6	4.1	2.0	5.3	0.1	1.6	98.75
13	1916	1917	3.2	10.5	8.3	10.2	7.7	10.6	9.2	0.9	3.6	0.6	0.5	3.9	69.31
14	1917	1918	1.6	5.1	24.4	10.4	10.8	8.7	2.9	2.6	0.0	0.8	3.9	0.1	71.35
15	1918	1919	6.7	10.3	14.7	14.5	11.2	10.2	6.2	4.0	1.7	0.0	0.3	3.1	83.00
17	1920	1921	13.2	8.9	13.9	18.1	12.2	6.7	8.0	2.4	5.6	0.1	2.1	4.3	95.47
18	1921	1922	10.9	16.3	9.4	4.9	6.2	9.9	5.5	4.0	0.6	0.0	2.2	4.4	74.12
21	1924	1925	13.4	11.1	14.6	16.6	11.5	5.4	3.9	1.6	3.2	0.4	1.2	1.6	84.50
22	1925	1926	2.6	11.0	14.1	10.4	10.5	4.5	2.3	7.9	0.1	0.2	3.1	3.4	69.96
27	1930	1931	6.5	6.7	6.7	15.7	9.2	14.8	5.6	2.5	6.4	0.1	0.5	7.2	81.88
28	1931	1932	12.0	10.6	17.9	11.8	15.5	16.9	8.5	2.1	1.2	4.8	1.8	2.0	105.17
30	1933	1934	11.3	7.0	35.7	19.3	6.3	8.4	2.3	4.8	0.8	2.3	1.1	4.4	103.58
31	1934	1935	12.1	14.9	15.1	20.4	8.1	14.9	3.6	1.7	2.6	1.0	1.9	4.4	100.55
32	1935	1936	4.6	6.1	8.7	15.2	12.4	7.7	2.3	6.3	6.0	2.5	2.1	1.3	75.26
33	1936	1937	2.0	1.5	14.5	6.1	14.8	5.3	12.5	4.0	5.9	0.2	5.2	3.9	75.91
34	1937	1938	5.9	26.4	18.1	9.2	7.7	12.7	9.5	3.3	0.2	0.4	0.6	2.9	96.86
35	1938	1939	8.8	10.6	12.0	16.6	10.5	5.9	2.1	3.6	3.3	1.9	1.1	1.3	77.63
36	1939	1940	5.5	6.5	18.9	9.5	17.3	10.9	7.6	3.4	0.3	3.0	1.2	2.7	86.80
37	1940	1941	12.2	9.1	9.9	10.0	4.6	3.0	2.4	6.4	2.7	0.1	4.3	7.8	72.41
38	1941	1942	4.9	8.8	15.5	7.3	6.0	5.7	4.1	3.2	4.3	2.7	0.3	0.6	63.48
39	1942	1943	8.2	13.3	14.2	8.3	8.5	8.2	6.9	3.6	2.2	1.3	3.4	2.2	80.10
40	1943	1944	9.4	4.6	12.6	9.3	6.6	5.4	7.3	2.6	0.5	0.4	1.1	5.4	65.15
41	1944	1945	3.5	11.1	5.1	13.4	9.4	12.3	3.8	5.1	0.7	0.8	0.5	5.5	71.08
42	1945	1946	4.5	14.2	13.3	12.5	13.8	7.9	8.3	0.9	5.1	1.9	0.3	2.2	84.80
43	1946	1947	8.5	9.9	12.5	11.9	8.3	4.6	4.9	1.5	5.4	3.5	1.0	2.3	74.35
44	1947	1948	17.4	7.9	13.0	8.4	12.0	7.3	6.3	8.5	1.2	1.3	3.0	7.2	93.33
45	1948	1949	5.9	14.6	14.7	1.4	14.6	6.7	4.0	2.2	1.2	1.4	1.3	2.4	70.38
46	1949	1950	6.8	13.6	14.6	11.0	15.3	14.3	6.9	2.5	1.2	1.4	2.5	3.6	93.64
47	1950	1951	12.4	12.1	16.2	14.6	13.8	8.0	1.9	1.9	0.3	0.5	0.1	4.3	86.15

Appendix Table I (continued). Water Years used in Degree of Wetness Analysis.

Ctr	Water Year		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total Precipitation (inches)
48	1951	1952	11.0	9.7	11.1	12.2	6.8	7.4	3.5	2.3	3.0	0.3	2.5	0.7	70.61
49	1952	1953	1.8	3.0	15.3	30.5	7.2	7.8	5.0	4.2	2.8	0.5	2.8	3.3	84.20
51	1954	1955	5.9	14.0	10.4	7.1	7.2	9.4	9.3	2.2	2.0	4.7	0.3	2.1	74.57
52	1955	1956	13.4	16.4	18.1	16.8	8.2	17.2	1.4	1.4	5.0	1.0	1.8	5.4	105.81
53	1956	1957	13.7	5.2	13.1	6.4	9.8	12.6	5.0	2.0	2.6	2.3	2.7	1.0	76.40
54	1957	1958	5.6	7.2	15.3	13.8	11.9	4.9	8.4	1.3	2.6	0.0	1.1	3.9	75.99
55	1958	1959	8.2	16.6	12.5	12.9	7.0	9.2	9.0	4.5	3.4	1.7	1.5	8.6	94.97
56	1959	1960	7.3	12.6	11.4	12.5	10.2	8.5	6.1	8.3	1.3	0.0	2.4	1.1	81.73
57	1960	1961	7.5	14.3	7.0	13.9	20.6	12.8	5.4	3.5	0.9	0.9	1.3	1.8	89.85
58	1961	1962	6.9	10.9	12.6	7.2	4.6	8.2	6.7	3.7	2.4	0.5	3.0	4.3	71.07
59	1962	1963	8.1	17.0	9.8	4.5	10.0	7.2	6.8	3.6	2.4	2.0	2.4	3.0	76.71
61	1964	1965	4.2	14.3	12.5	19.1	11.4	1.6	4.9	3.9	0.8	0.5	3.1	1.0	77.10
62	1965	1966	6.5	11.4	11.2	13.1	8.8	11.4	3.2	2.3	2.5	0.5	1.1	2.1	74.09
63	1966	1967	7.9	9.6	20.8	19.3	8.8	10.4	5.5	1.2	1.1	0.3	0.2	2.6	87.51
64	1967	1968	16.4	7.9	13.1	13.1	9.7	12.3	5.1	4.0	5.9	0.9	4.0	4.5	96.91
65	1968	1969	8.4	10.8	16.5	12.5	7.5	4.9	6.8	3.8	2.8	0.3	0.7	6.4	81.29
66	1969	1970	5.0	6.8	13.3	13.8	7.9	6.8	8.5	3.7	0.9	1.0	0.6	5.5	73.88
67	1970	1971	7.8	9.4	19.2	19.4	7.9	14.8	5.4	2.9	2.8	0.9	1.3	6.7	98.44
68	1971	1972	5.7	10.9	15.4	13.0	13.6	12.0	10.3	1.0	1.4	4.2	0.6	6.0	94.05
69	1972	1973	2.0	8.1	14.0	11.0	3.8	6.7	2.8	4.8	4.8	0.2	0.4	4.4	62.98
70	1973	1974	6.5	14.9	16.8	18.1	11.8	15.2	7.4	5.3	2.6	3.0	0.8	0.7	103.09
71	1974	1975	2.5	9.3	15.4	12.7	9.1	7.6	3.4	4.5	2.5	0.2	5.2	0.1	72.42
72	1975	1976	17.8	14.2	20.3	15.3	10.3	10.4	3.6	2.9	2.1	2.4	3.7	1.4	104.40
73	1976	1977	3.1	3.3	5.7	3.5	6.4	11.0	2.5	6.8	1.6	1.0	5.4	5.4	55.77
74	1977	1978	6.1	14.6	18.0	7.0	5.9	6.0	4.8	5.2	3.6	0.6	3.2	10.2	85.21
75	1978	1979	1.3	6.2	5.5	3.7	18.3	5.0	5.1	2.7	1.3	2.3	1.8	3.3	56.28
76	1979	1980	10.1	4.8	18.9	6.2	13.4	6.4	6.4	2.0	2.0	0.9	1.4	3.7	76.22
77	1980	1981	2.6	14.9	13.2	3.7	13.0	6.1	12.2	3.8	5.0	1.2	0.7	7.4	83.78
78	1981	1982	11.1	10.5	15.8	18.1	16.4	8.9	9.9	0.6	2.3	1.3	0.9	2.8	98.59
79	1982	1983	8.7	11.1	16.2	17.3	14.7	12.7	3.8	2.8	3.3	5.1	1.1	3.6	100.31
80	1983	1984	2.9	23.8	9.8	14.7	11.0	7.9	5.6	7.8	4.2	0.1	0.8	3.8	92.28
81	1984	1985	8.9	18.0	8.8	0.6	5.7	8.8	6.4	2.4	3.1	0.2	1.3	3.9	67.96
82	1985	1986	14.6	7.9	3.2	16.6	12.0	6.2	5.5	5.4	1.6	2.7	0.1	3.5	79.24
84	1987	1988	0.5	5.9	13.3	8.8	4.3	11.5	6.5	5.8	2.2	1.5	0.8	3.0	64.07
85	1988	1989	5.1	14.3	9.9	10.4	6.9	10.2	4.4	3.3	1.7	2.6	1.3	0.7	70.78

Appendix Table I (continued). Water Years used in Degree of Wetness Analysis.

Ctr	Water Year		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total Precipitation (inches)
86	1989	1990	7.2	13.7	8.3	19.6	16.3	7.6	5.5	3.5	3.8	0.4	1.7	0.0	87.53
87	1990	1991	12.0	24.0	10.7	10.8	14.2	6.6	10.2	3.3	1.6	0.7	7.1	0.0	101.18
88	1991	1992	2.9	14.5	8.6	16.6	6.3	1.4	8.7	0.4	1.3	0.8	1.3	2.9	65.59
89	1992	1993	5.8	11.5	8.5	9.1	0.6	8.8	9.6	5.2	4.1	1.9	0.4	0.0	65.51
90	1993	1994	3.5	4.2	14.0	10.6	12.1	7.9	4.8	3.1	3.8	0.8	1.0	2.3	68.05
92	1995	1996	10.8	22.7	13.2	12.9	13.2	2.8	11.6	3.7	1.1	1.0	1.0	3.8	97.82
93	1996	1997	12.4	10.1	23.1	16.5	6.9	21.9	7.7	5.7	4.5	2.5	2.5	6.9	120.48
94	1997	1998	13.5	8.3	10.0	20.0	9.4	8.6	2.4	2.6	1.5	1.4	0.1	0.7	78.64
95	1998	1999	4.2	22.5	24.2	17.1	26.6	11.3	3.0	3.4	2.7	1.3	1.5	0.4	118.05
97	2000	2001	5.9	4.3	6.5	7.1	4.6	6.7	5.5	4.4	3.8	0.9	4.5	1.1	55.27
98	2001	2002	7.2	17.6	20.1	18.0	7.8	8.4	6.5	2.4	2.6	0.3	0.0	1.7	92.52
99	2002	2003	1.0	9.5	15.6	16.0	4.9	16.9	7.6	1.7	0.7	0.3	0.1	2.4	76.61
100	2003	2004	17.3	15.7	9.4	12.7	7.9	6.2	2.3	4.0	1.6	0.2	4.3	4.3	86.09
101	2004	2005	7.3	7.3	10.2	10.6	1.6	10.6	7.9	5.4	1.9	2.0	0.4	2.8	67.82
102	2005	2006	7.8	10.9	14.8	26.8	6.0	7.6	3.7	3.6	2.6	0.5	0.3	1.4	86.07
103	2006	2007	3.0	30.5	14.5	10.7	11.3	12.4	3.7	2.2	3.1	3.0	1.0	1.5	96.72
105	2008	2009	4.4	17.0	9.6	14.4	4.2	7.6	4.8	7.4	0.4	0.6	1.5	2.0	73.66
106	2009	2010	12.1	23.9	5.7	15.0	8.9	6.9	7.1	5.9	3.7	0.4	0.6	5.1	95.34
107	2010	2011	10.6	12.0	16.4	14.1	8.0	17.3	8.5	4.7	1.5	1.9	0.3	3.0	98.35
108	2011	2012	7.6	12.3	5.1	12.4	9.5	15.5	7.6	4.9	4.0	1.3	0.1	0.1	80.45
109	2012	2013	15.3	16.5	18.6	9.0	6.2	8.3	8.8	4.4	2.9	0.0	1.6	8.9	100.34
110	2013	2014	2.4	6.2	5.7	7.9	10.5	16.0	6.9	6.4	1.1	0.7	2.0	3.8	69.64
111	2014	2015	12.3	10.6	12.7	13.3	8.3	8.5	3.3	0.4	0.3	0.4	2.6	2.7	75.29
112	2015	2016	7.6	15.6	21.0	17.2	10.0	17.6	2.7	1.1	3.1	0.5	0.8	3.6	100.93

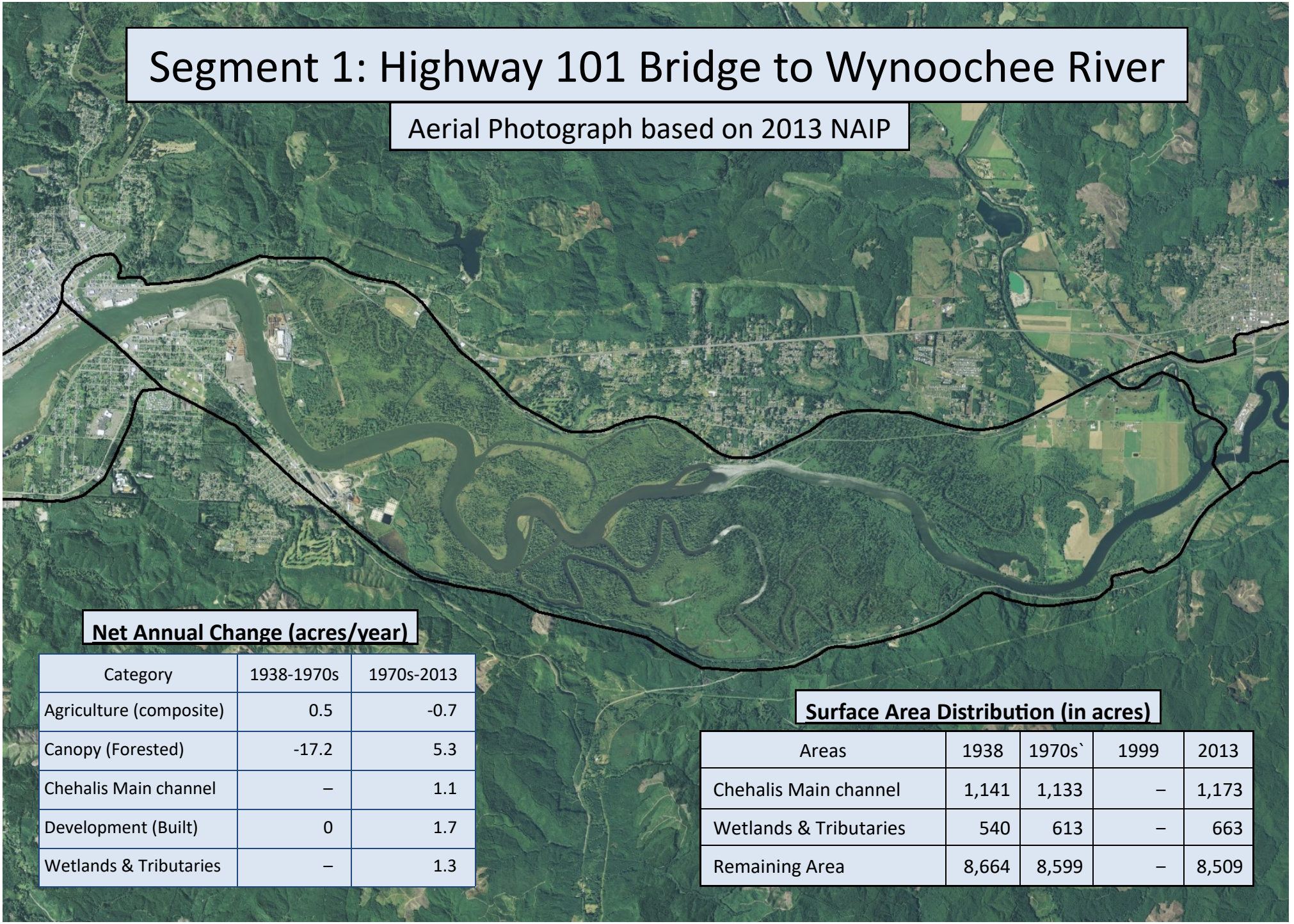
Appendix III. Habitat and Change Analysis Maps by Segment

This appendix provides habitat and change analysis maps by segment. For each segment, the following five maps are provided:

1) The 2013 aerial photograph with two tables: a) acreages of Chehalis Main channel, Wetlands and Tributaries, and Remaining Area; and b) net annual change in acres per year for Agriculture, Canopy (forested), Chehalis Main channel, Development (Built), and Wetland and Tributaries.
2) The 2013 land cover map with acreages for each land cover class.
3) Water surface by years visibility map color-coded across visibility categories.
4) Land cover gains in acres for Agriculture, Canopy (forested), and Development (Built)
5) Land cover losses in acres for Agiculture, Canopy (forested), and Development (Built)

Segment 1: Highway 101 Bridge to Wynoochee River

Aerial Photograph based on 2013 NAIP



Net Annual Change (acres/year)

Category	1938-1970s	1970s-2013
Agriculture (composite)	0.5	-0.7
Canopy (Forested)	-17.2	5.3
Chehalis Main channel	–	1.1
Development (Built)	0	1.7
Wetlands & Tributaries	–	1.3

Surface Area Distribution (in acres)

Areas	1938	1970s`	1999	2013
Chehalis Main channel	1,141	1,133	–	1,173
Wetlands & Tributaries	540	613	–	663
Remaining Area	8,664	8,599	–	8,509

Segment 1: Highway 101 Bridge to Wynoochee River

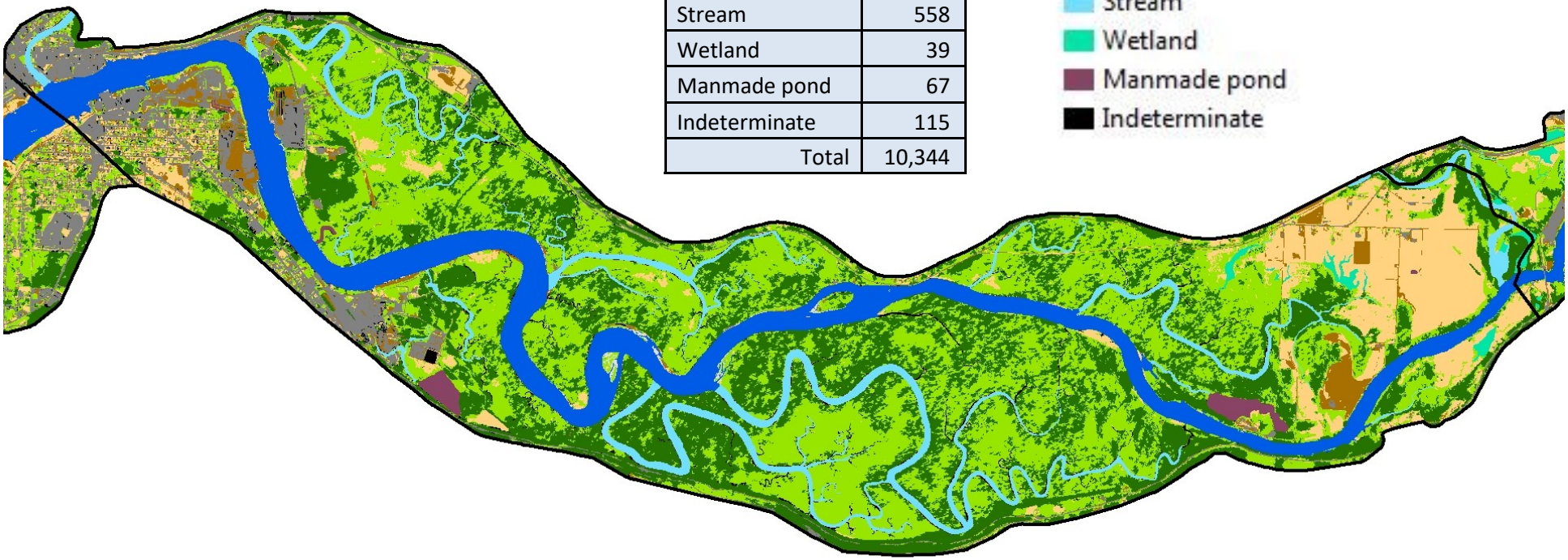
2013 Land Cover

Land Cover Totals

Land Class	Acres
Built	619
Ground	294
Herbaceous	947
Shrub/Small Tree	3,723
Forested	2,848
Main Channel	1,117
Sand/Gravel	17
Stream	558
Wetland	39
Manmade pond	67
Indeterminate	115
Total	10,344

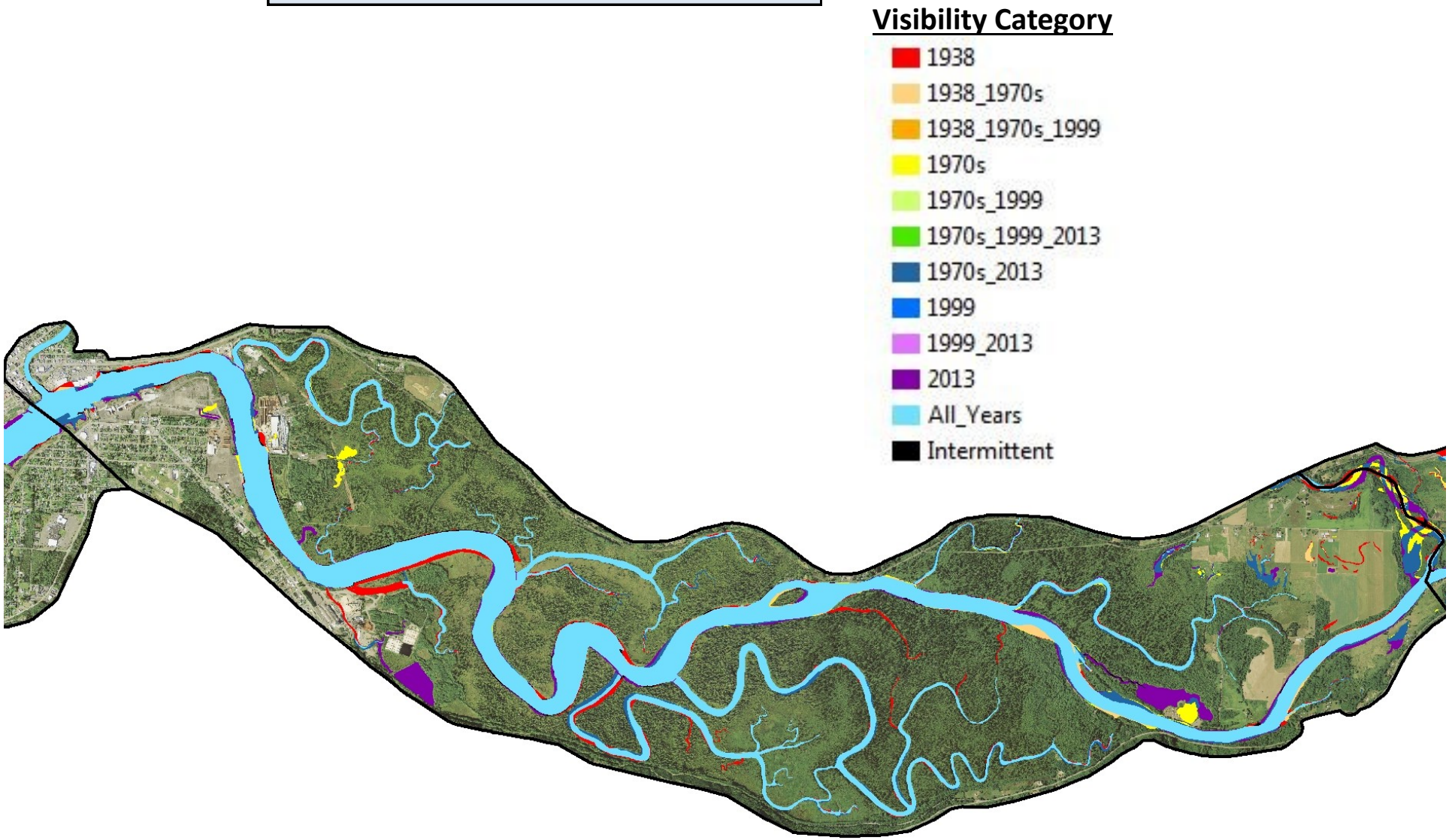
Land Class

- Built
- Ground
- Herbaceous
- Shrub/Small Tree
- Forested
- Main Channel
- Sand/Gravel
- Stream
- Wetland
- Manmade pond
- Indeterminate



Segment 1: Highway 101 Bridge to Wynoochee River

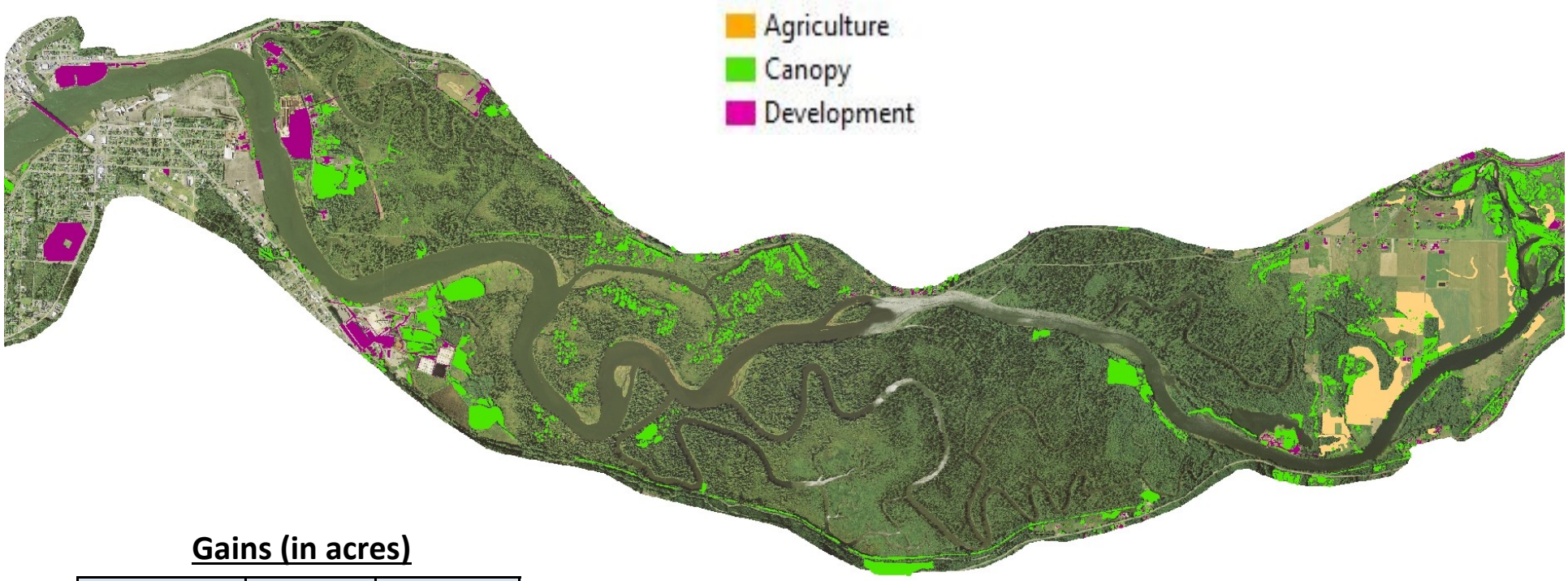
Water Surface by Years Visible



Segment 1: Highway 101 Bridge to Wynoochee River

Land Cover Gains

Gains represents areas that converted to the indicated category (color-coded below) during one or more of the measured time periods.



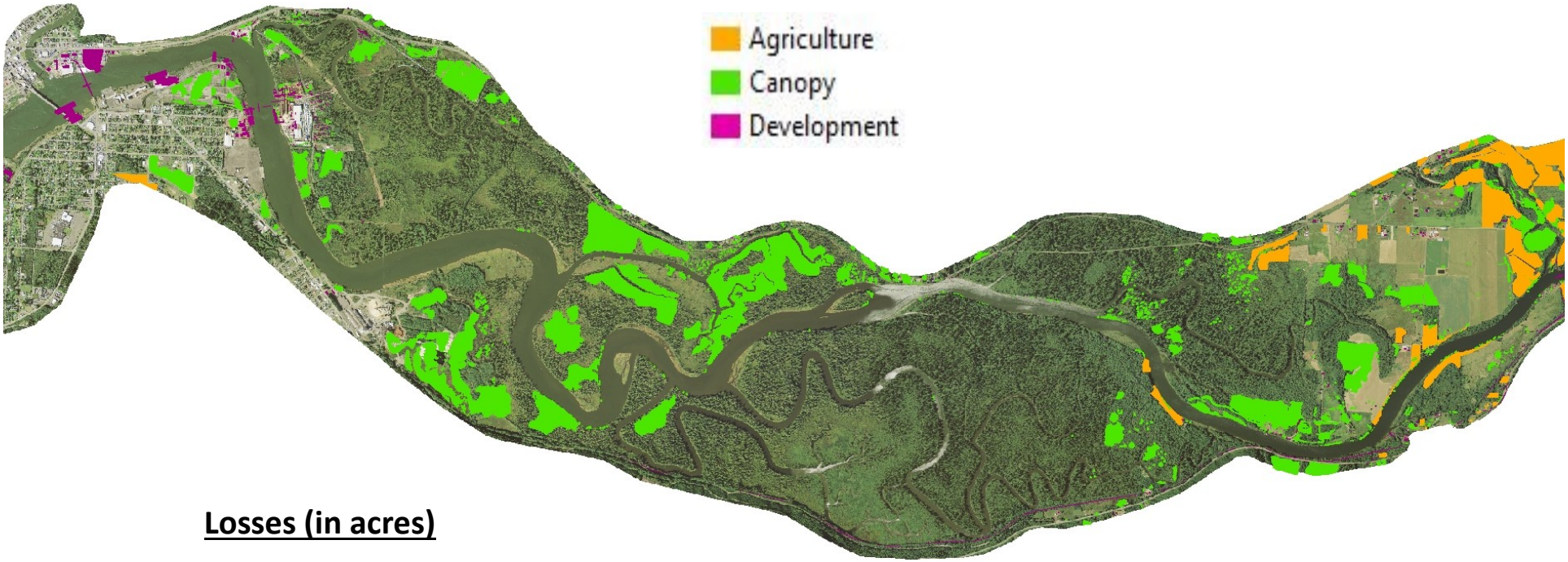
Gains (in acres)

Category	1938-1970s	1970s-2013
Agriculture	112.0	33.1
Canopy	52.3	470.3
Development	41.9	97.0

Segment 1: Highway 101 Bridge to Wynoochee River

Land Cover Losses

Losses represent areas that converted from the indicated category (color-coded below) to another category during one or more of the measured time periods.

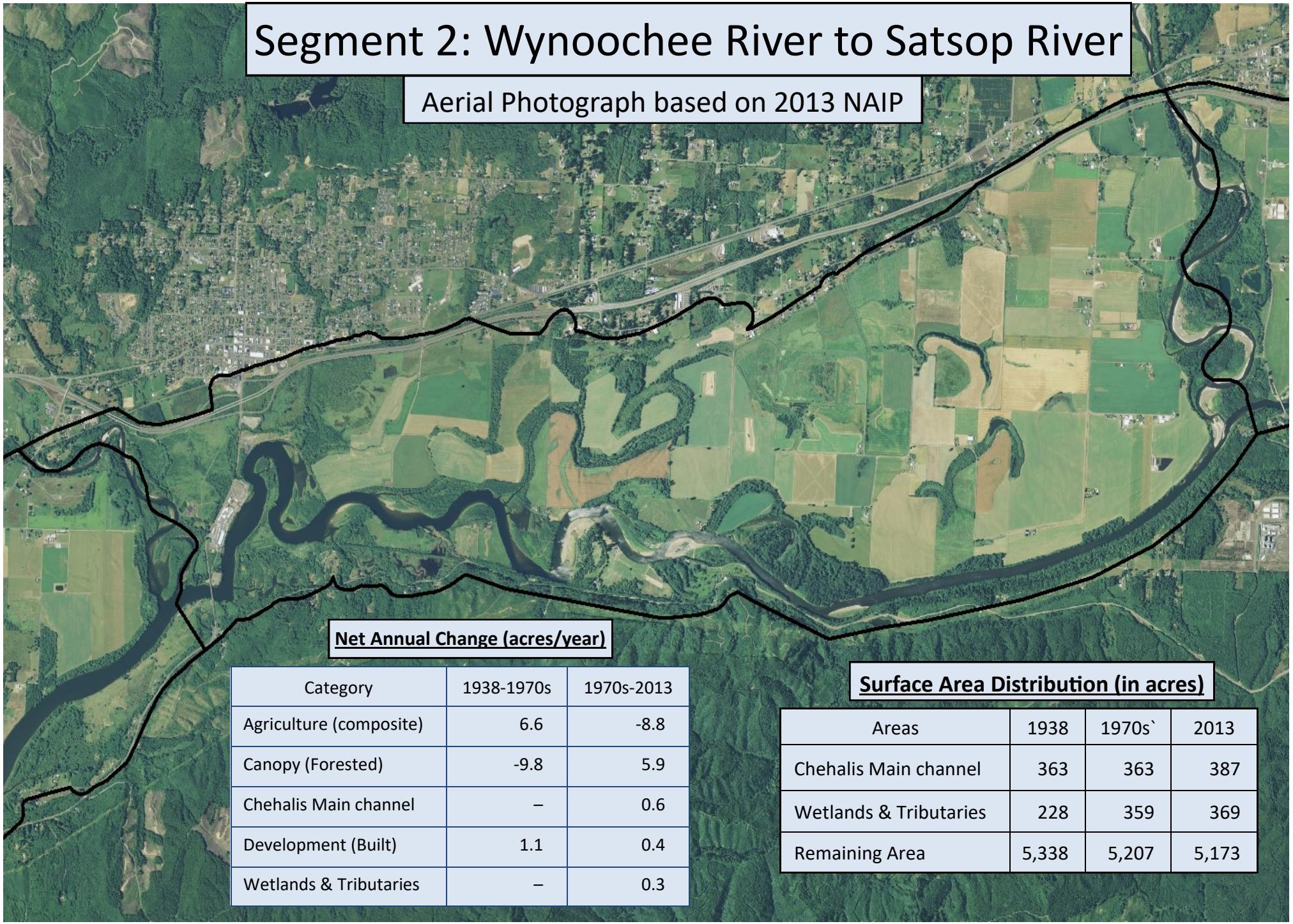


Losses (in acres)

Category	1938-1970s	1970s-2013
Agriculture	92.5	60.6
Canopy	691.4	269.2
Development	43.4	32.4

Segment 2: Wynoochee River to Satsop River

Aerial Photograph based on 2013 NAIP



Net Annual Change (acres/year)

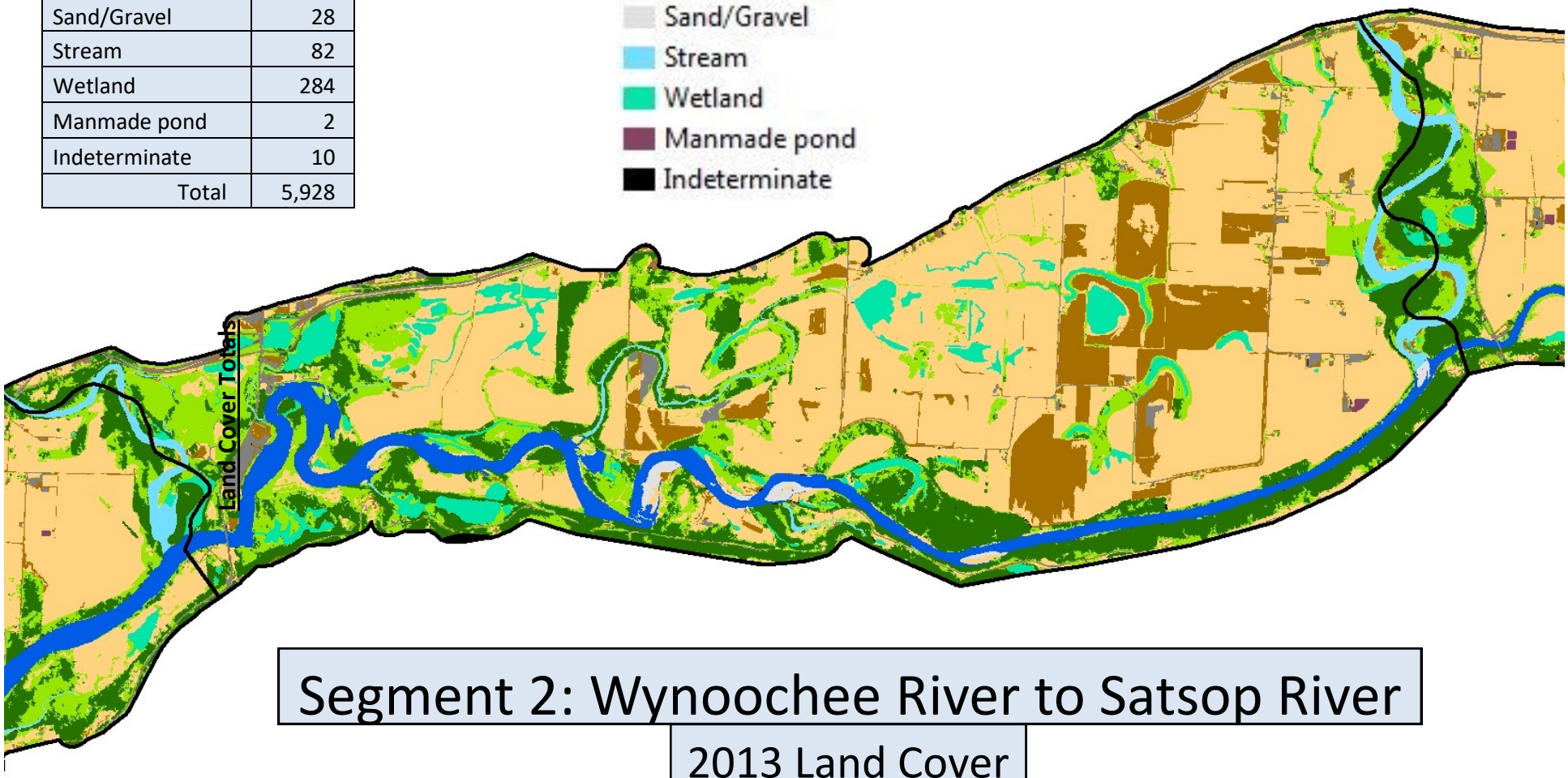
Category	1938-1970s	1970s-2013
Agriculture (composite)	6.6	-8.8
Canopy (Forested)	-9.8	5.9
Chehalis Main channel	–	0.6
Development (Built)	1.1	0.4
Wetlands & Tributaries	–	0.3

Surface Area Distribution (in acres)

Areas	1938	1970s`	2013
Chehalis Main channel	363	363	387
Wetlands & Tributaries	228	359	369
Remaining Area	5,338	5,207	5,173

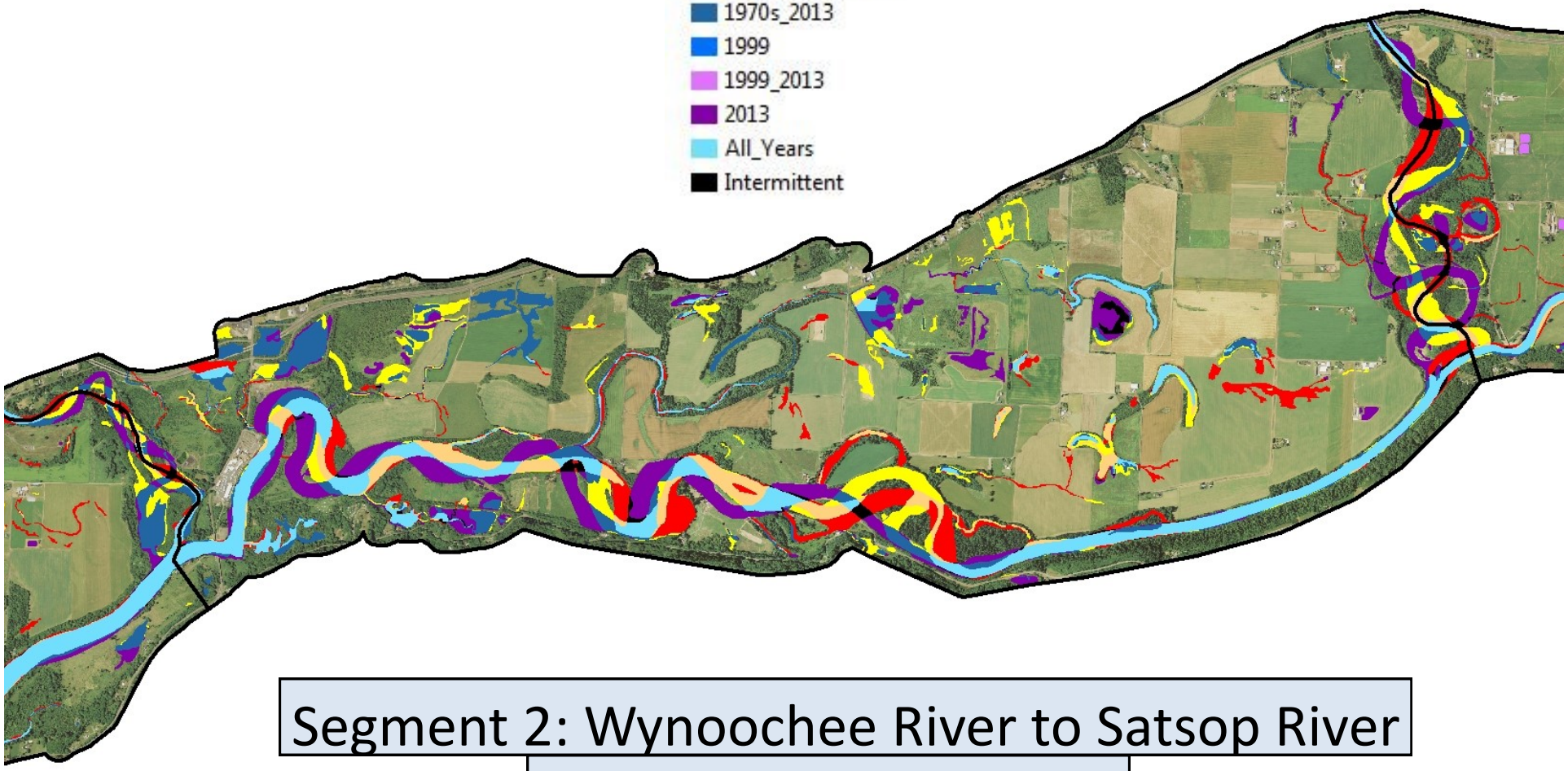
Land Cover Totals

Land Class	Acres
Built	158
Ground	608
Herbaceous	2,735
Shrub/Small Tree	809
Forested	887
Main Channel	325
Sand/Gravel	28
Stream	82
Wetland	284
Manmade pond	2
Indeterminate	10
Total	5,928



Segment 2: Wynoochee River to Satsop River

2013 Land Cover



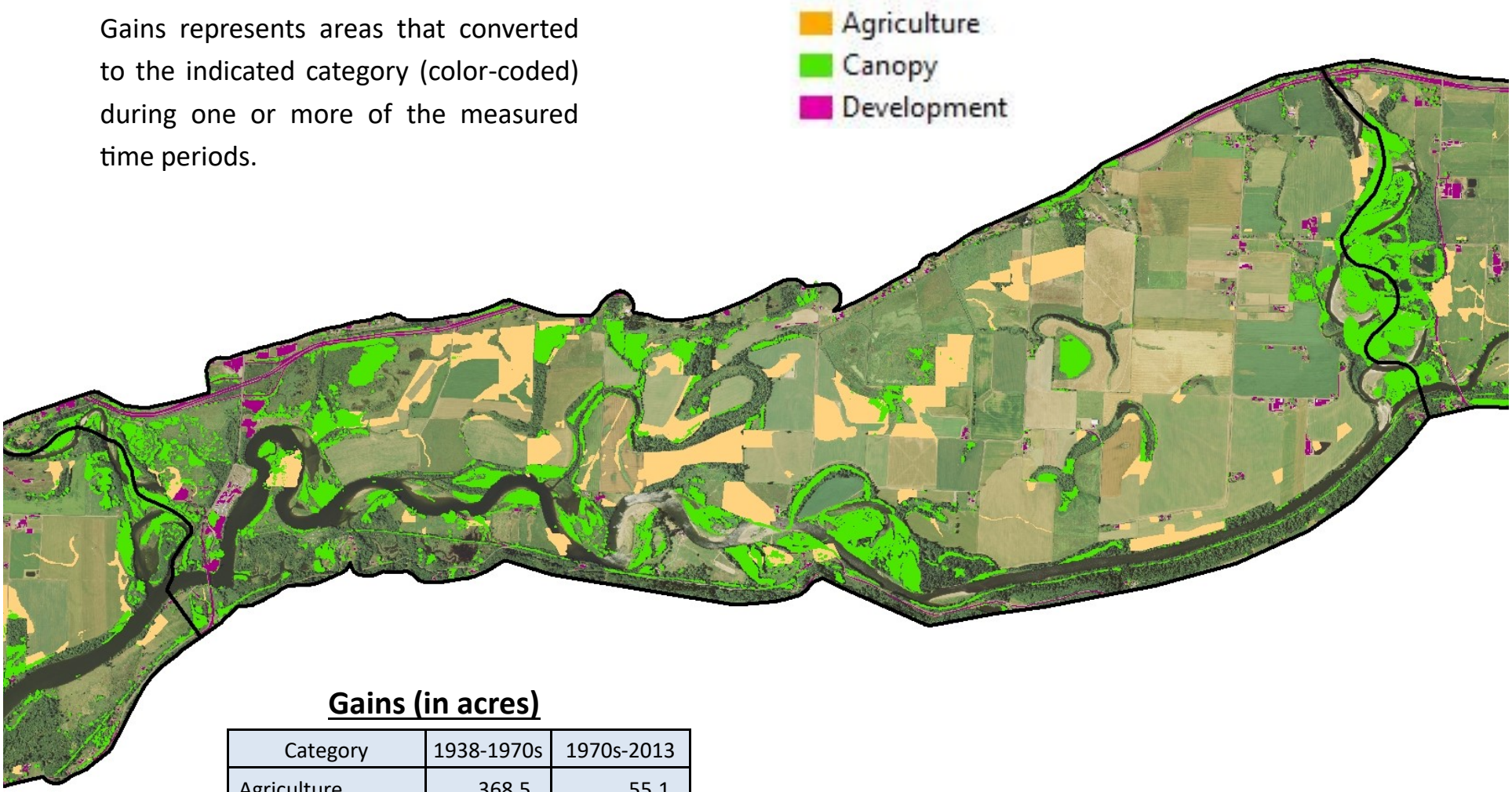
Segment 2: Wynoochee River to Satsop River

Water Surface by Years Visible

Segment 2: Wynoochee River to Satsop River

Land Cover Gains

Gains represents areas that converted to the indicated category (color-coded) during one or more of the measured time periods.



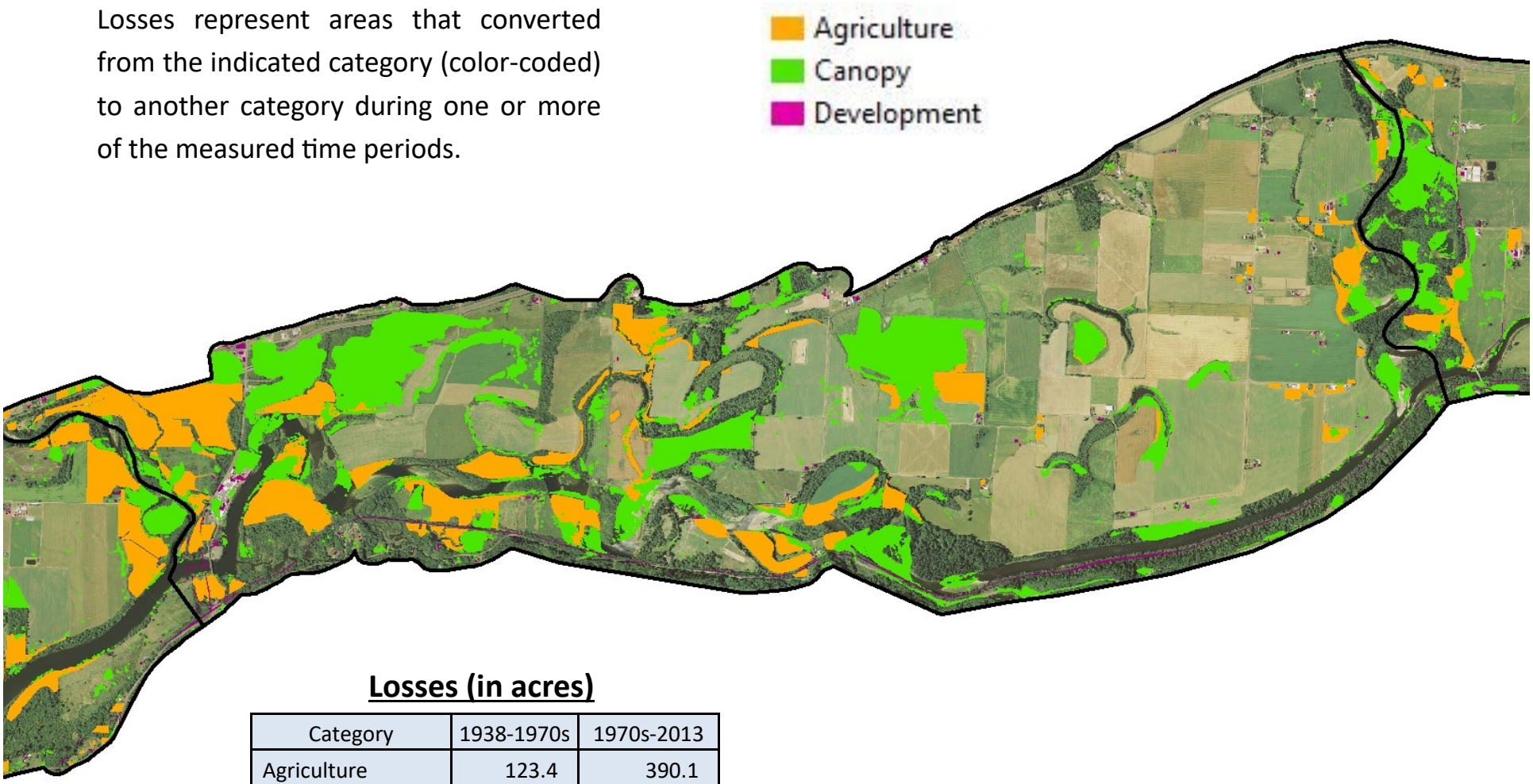
Gains (in acres)

Category	1938-1970s	1970s-2013
Agriculture	368.5	55.1
Canopy	181.8	423.4
Development	50.6	46.0

Segment 2: Wynoochee River to Satsop River

Land Cover Losses

Losses represent areas that converted from the indicated category (color-coded) to another category during one or more of the measured time periods.

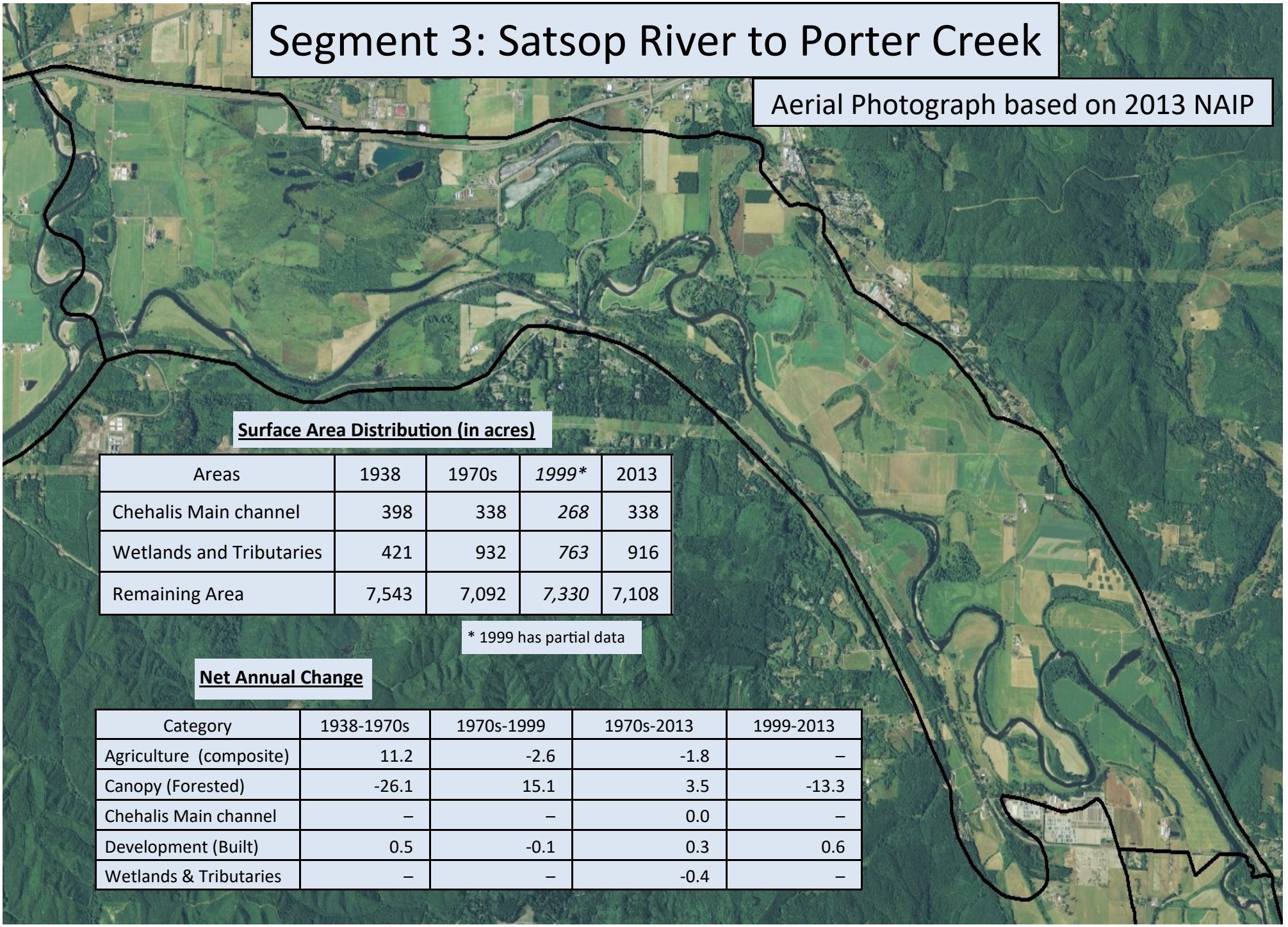


Losses (in acres)

Category	1938-1970s	1970s-2013
Agriculture	123.4	390.1
Canopy	543.9	199.8
Development	9.8	29.1

Segment 3: Satsop River to Porter Creek

Aerial Photograph based on 2013 NAIP



Surface Area Distribution (in acres)

Areas	1938	1970s	*1999**	2013
Chehalis Main channel	398	338	*268*	338
Wetlands and Tributaries	421	932	*763*	916
Remaining Area	7,543	7,092	*7,330*	7,108

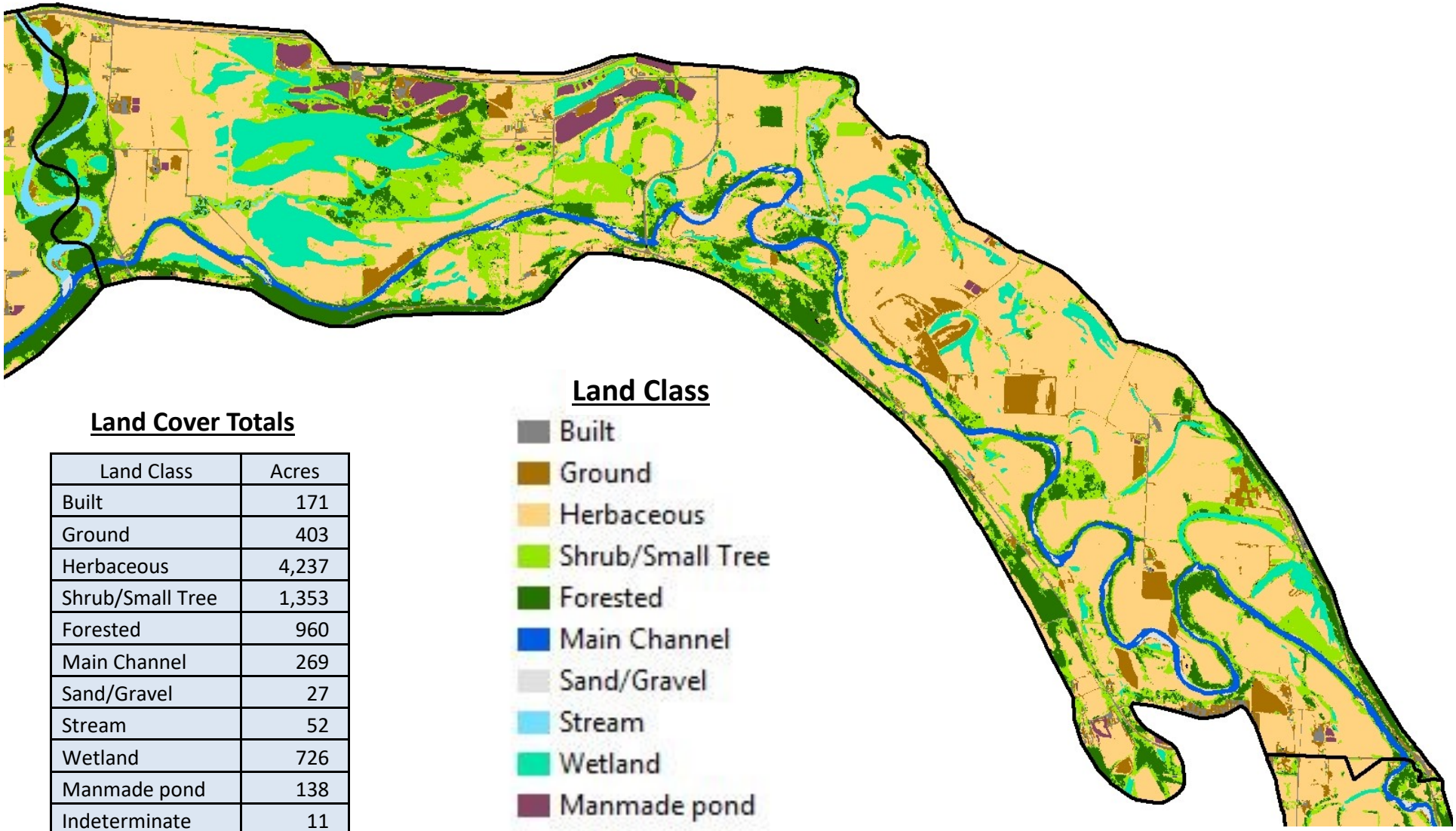
* 1999 has partial data

Net Annual Change

Category	1938-1970s	1970s-1999	1970s-2013	1999-2013
Agriculture (composite)	11.2	-2.6	-1.8	–
Canopy (Forested)	-26.1	15.1	3.5	-13.3
Chehalis Main channel	–	–	0.0	–
Development (Built)	0.5	-0.1	0.3	0.6
Wetlands & Tributaries	–	–	-0.4	–

Segment 3: Satsop River to Porter Creek

2013 Land Cover

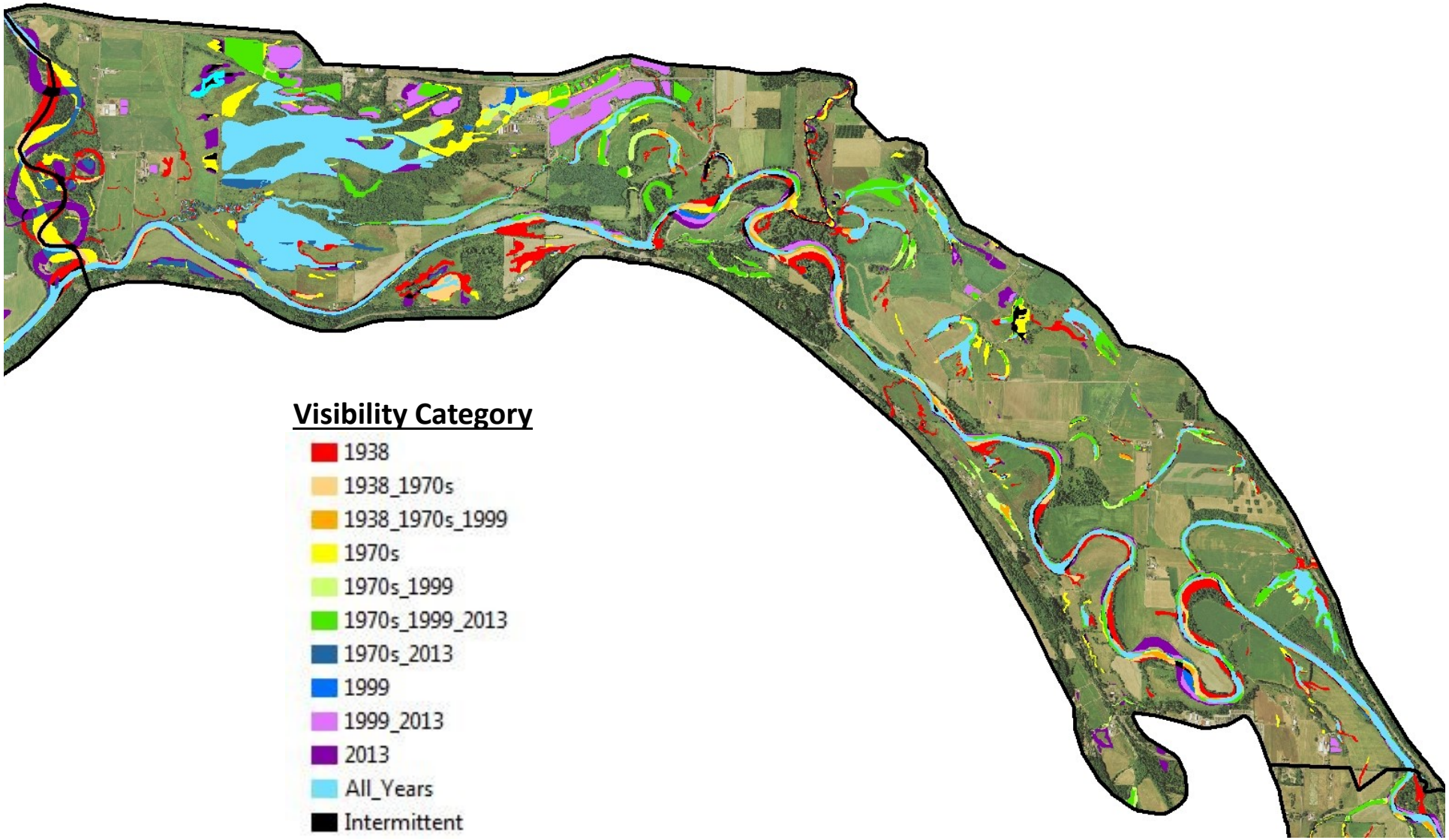


Land Cover Totals

Land Class	Acres
Built	171
Ground	403
Herbaceous	4,237
Shrub/Small Tree	1,353
Forested	960
Main Channel	269
Sand/Gravel	27
Stream	52
Wetland	726
Manmade pond	138
Indeterminate	11
Total	8,347

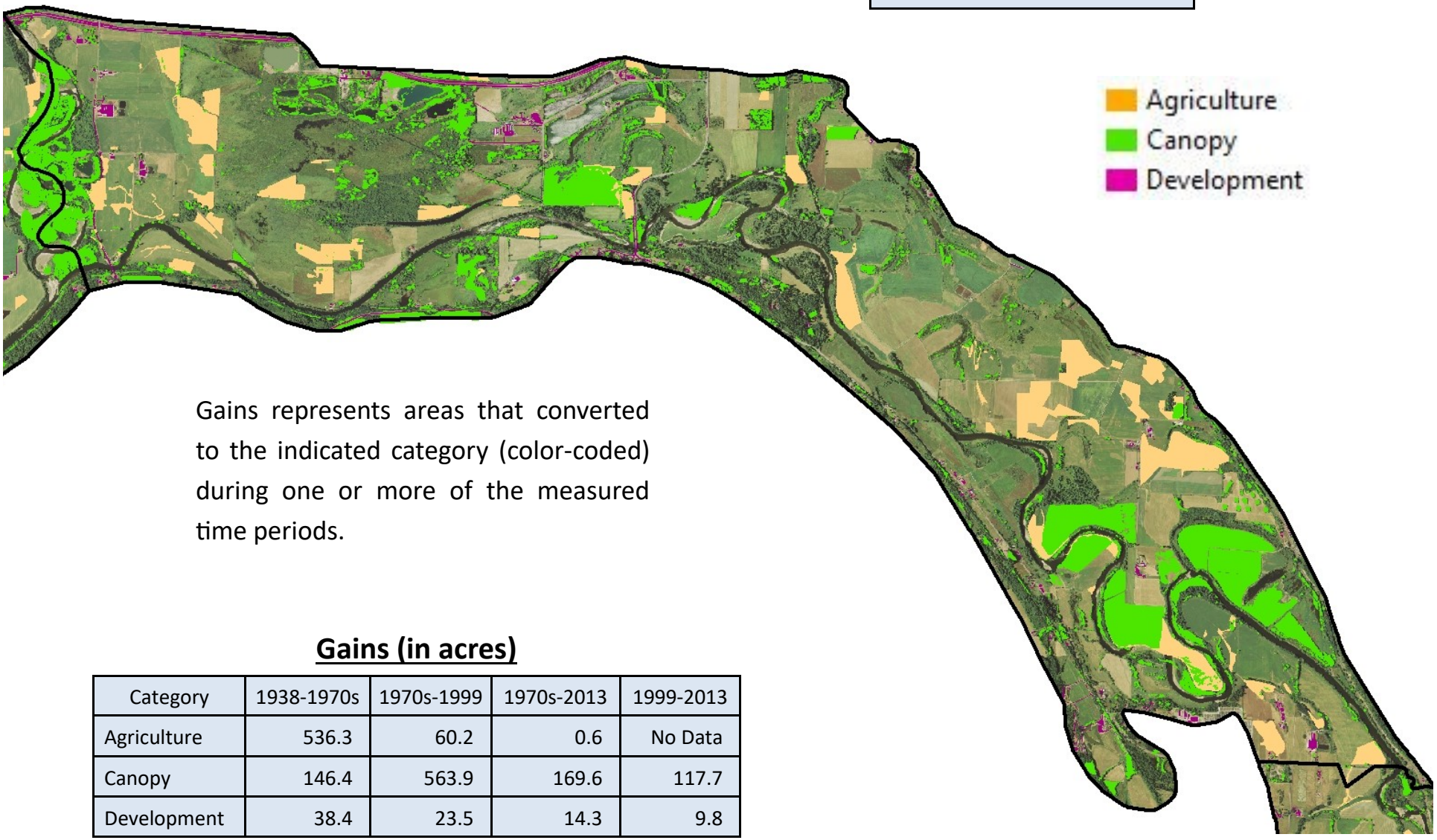
Segment 3: Satsop River to Porter Creek

Water Surface by Years Visible



Segment 3: Satsop River to Porter Creek

Land Cover Gains



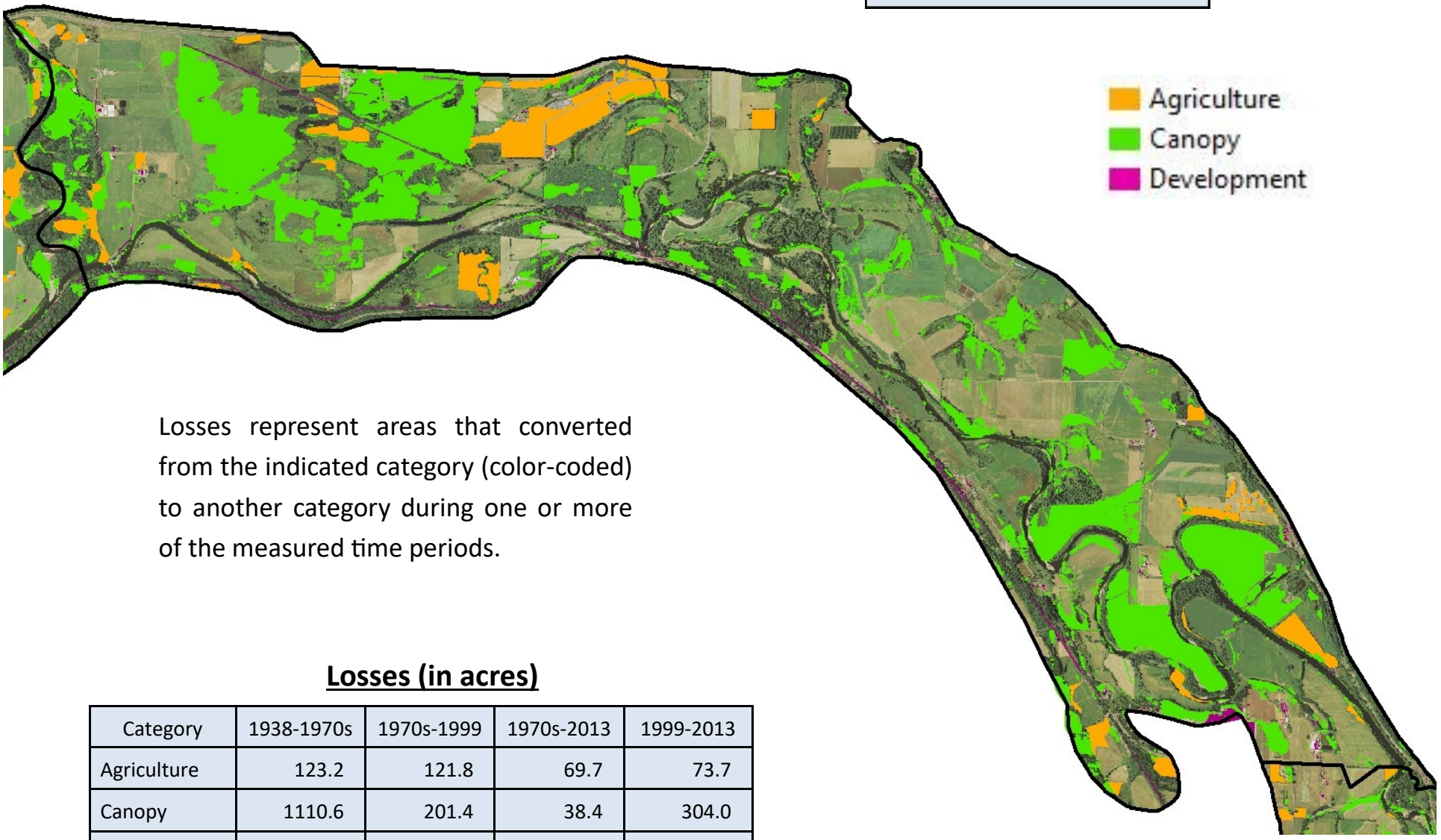
Gains represents areas that converted to the indicated category (color-coded) during one or more of the measured time periods.

Gains (in acres)

Category	1938-1970s	1970s-1999	1970s-2013	1999-2013
Agriculture	536.3	60.2	0.6	No Data
Canopy	146.4	563.9	169.6	117.7
Development	38.4	23.5	14.3	9.8

Segment 3: Satsop River to Porter Creek

Land Cover Losses



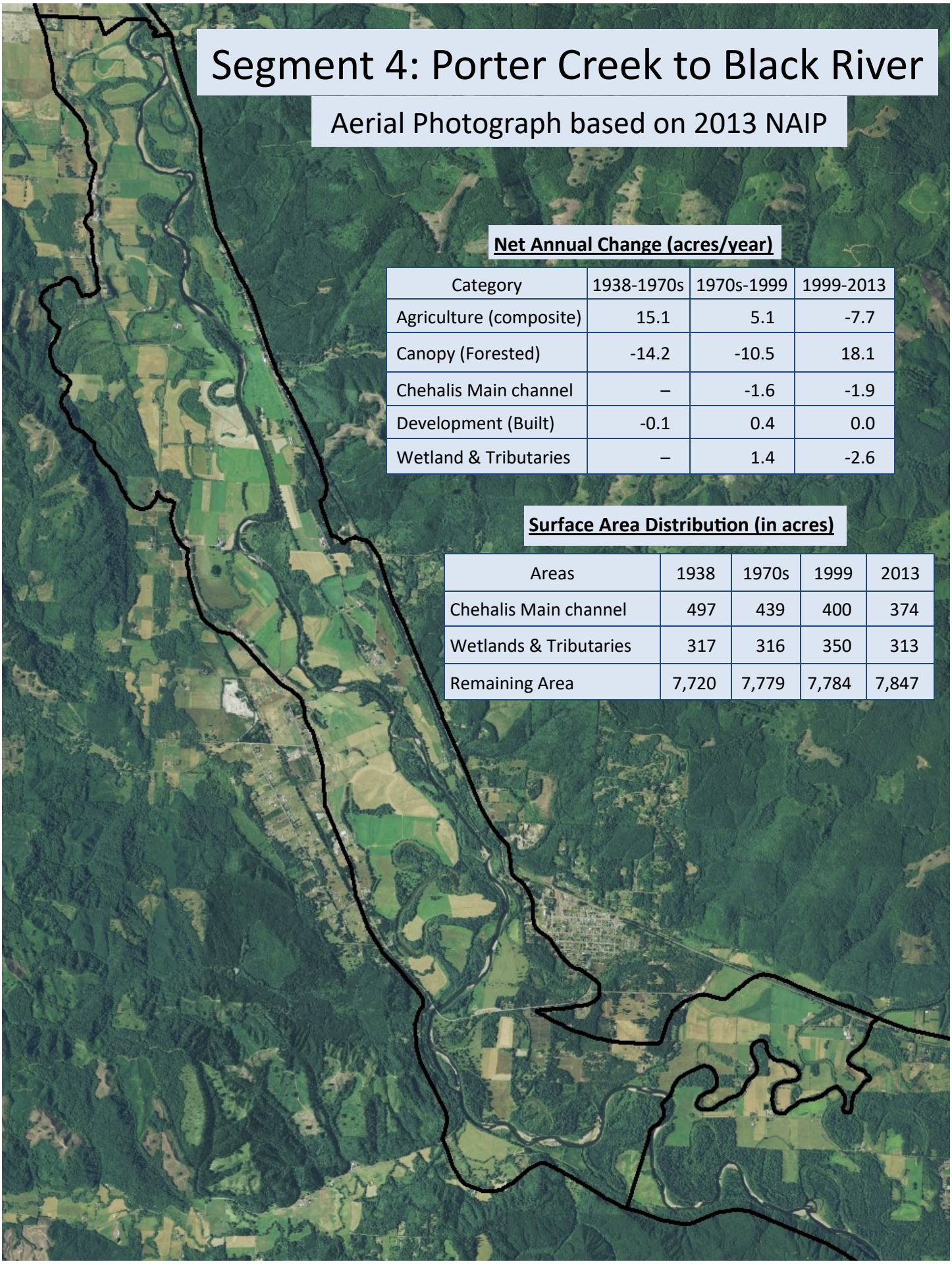
Losses represent areas that converted from the indicated category (color-coded) to another category during one or more of the measured time periods.

Losses (in acres)

Category	1938-1970s	1970s-1999	1970s-2013	1999-2013
Agriculture	123.2	121.8	69.7	73.7
Canopy	1110.6	201.4	38.4	304.0
Development	19.5	25.3	2.1	1.6

Segment 4: Porter Creek to Black River

Aerial Photograph based on 2013 NAIP



Net Annual Change (acres/year)

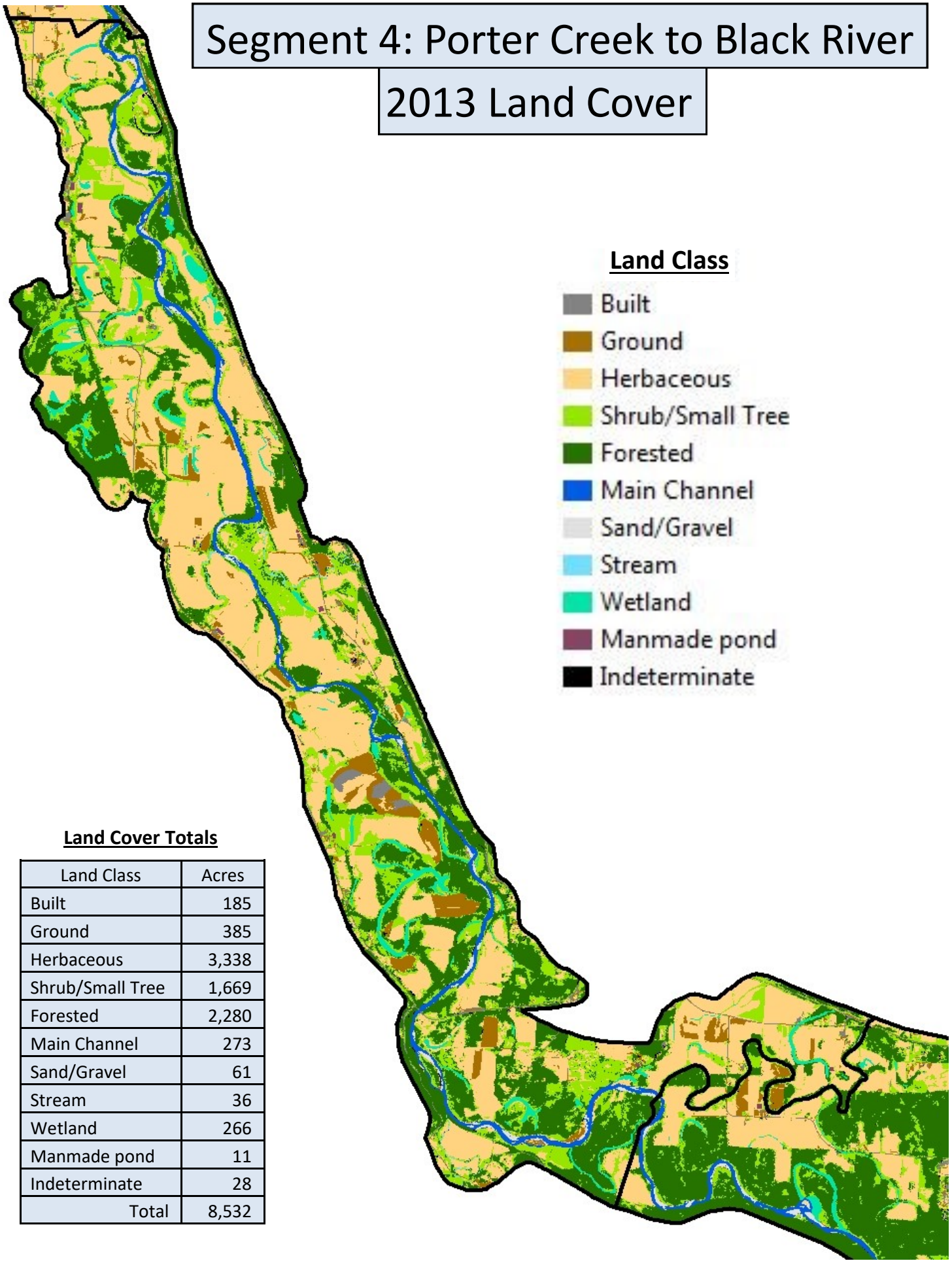
Category	1938-1970s	1970s-1999	1999-2013
Agriculture (composite)	15.1	5.1	-7.7
Canopy (Forested)	-14.2	-10.5	18.1
Chehalis Main channel	–	-1.6	-1.9
Development (Built)	-0.1	0.4	0.0
Wetland & Tributaries	–	1.4	-2.6

Surface Area Distribution (in acres)

Areas	1938	1970s	1999	2013
Chehalis Main channel	497	439	400	374
Wetlands & Tributaries	317	316	350	313
Remaining Area	7,720	7,779	7,784	7,847

Segment 4: Porter Creek to Black River

2013 Land Cover

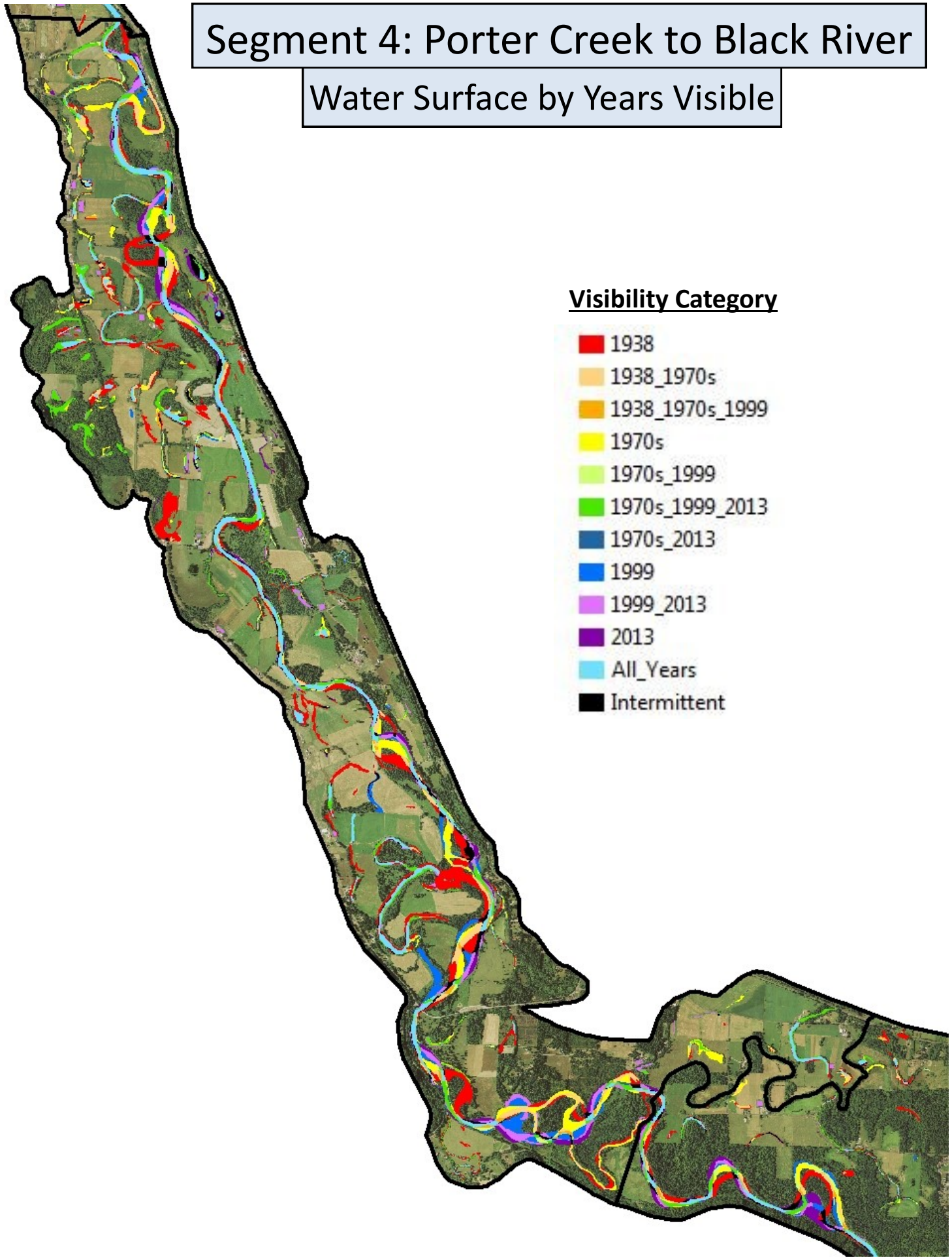


Land Cover Totals

Land Class	Acres
Built	185
Ground	385
Herbaceous	3,338
Shrub/Small Tree	1,669
Forested	2,280
Main Channel	273
Sand/Gravel	61
Stream	36
Wetland	266
Manmade pond	11
Indeterminate	28
Total	8,532

Segment 4: Porter Creek to Black River

Water Surface by Years Visible



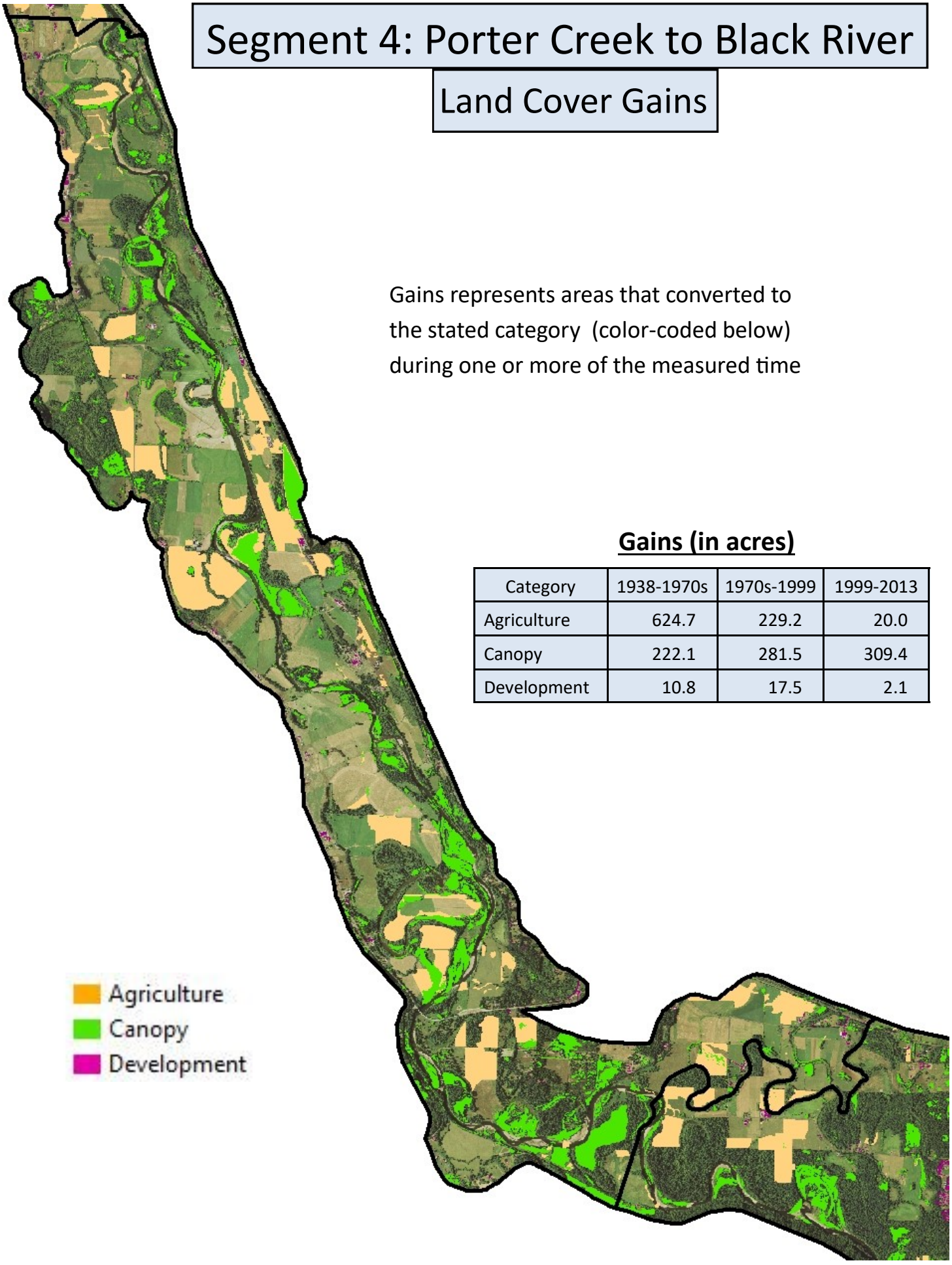
Segment 4: Porter Creek to Black River

Land Cover Gains

Gains represents areas that converted to the stated category (color-coded below) during one or more of the measured time

Gains (in acres)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture	624.7	229.2	20.0
Canopy	222.1	281.5	309.4
Development	10.8	17.5	2.1



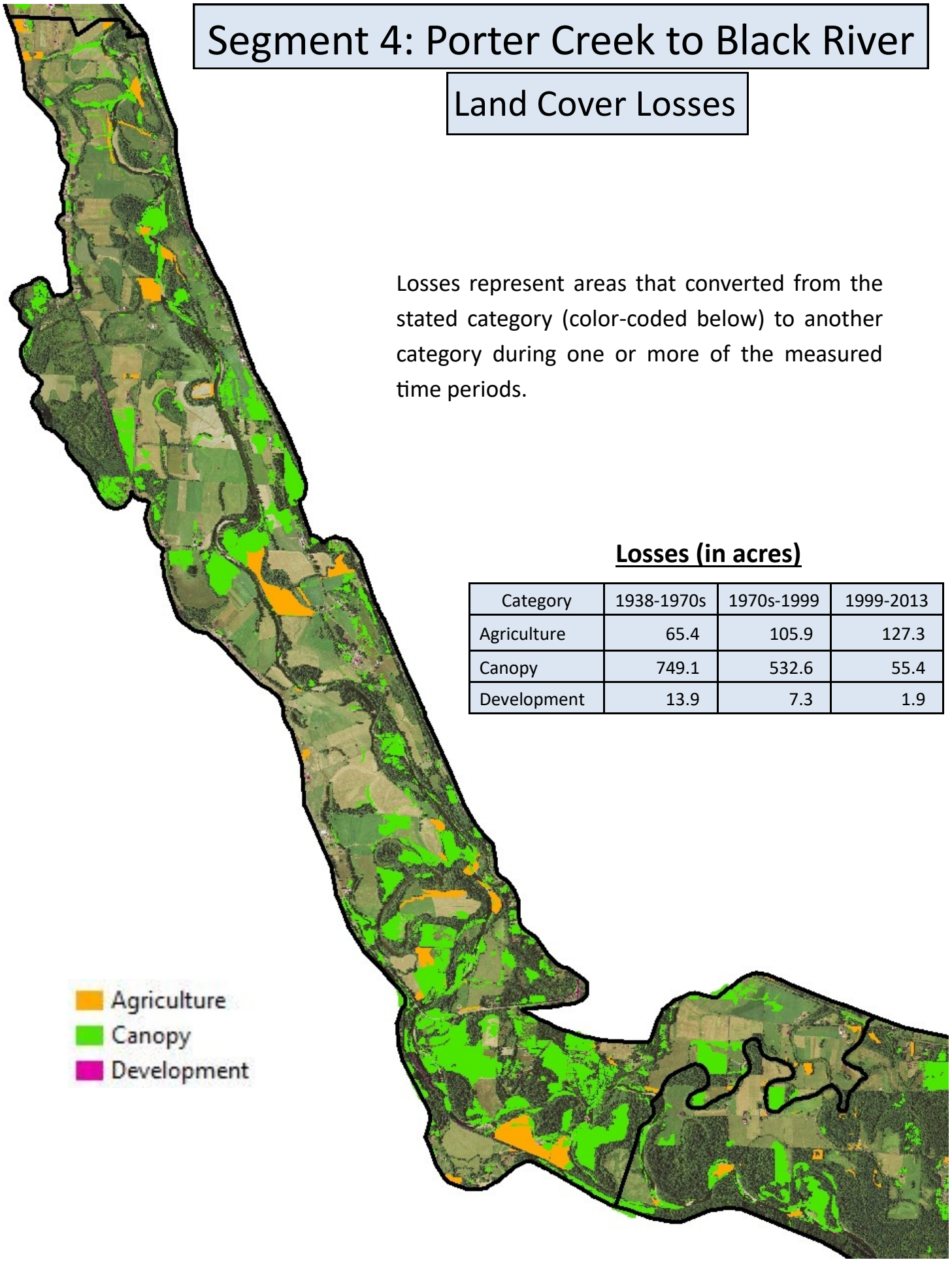
Segment 4: Porter Creek to Black River

Land Cover Losses

Losses represent areas that converted from the stated category (color-coded below) to another category during one or more of the measured time periods.

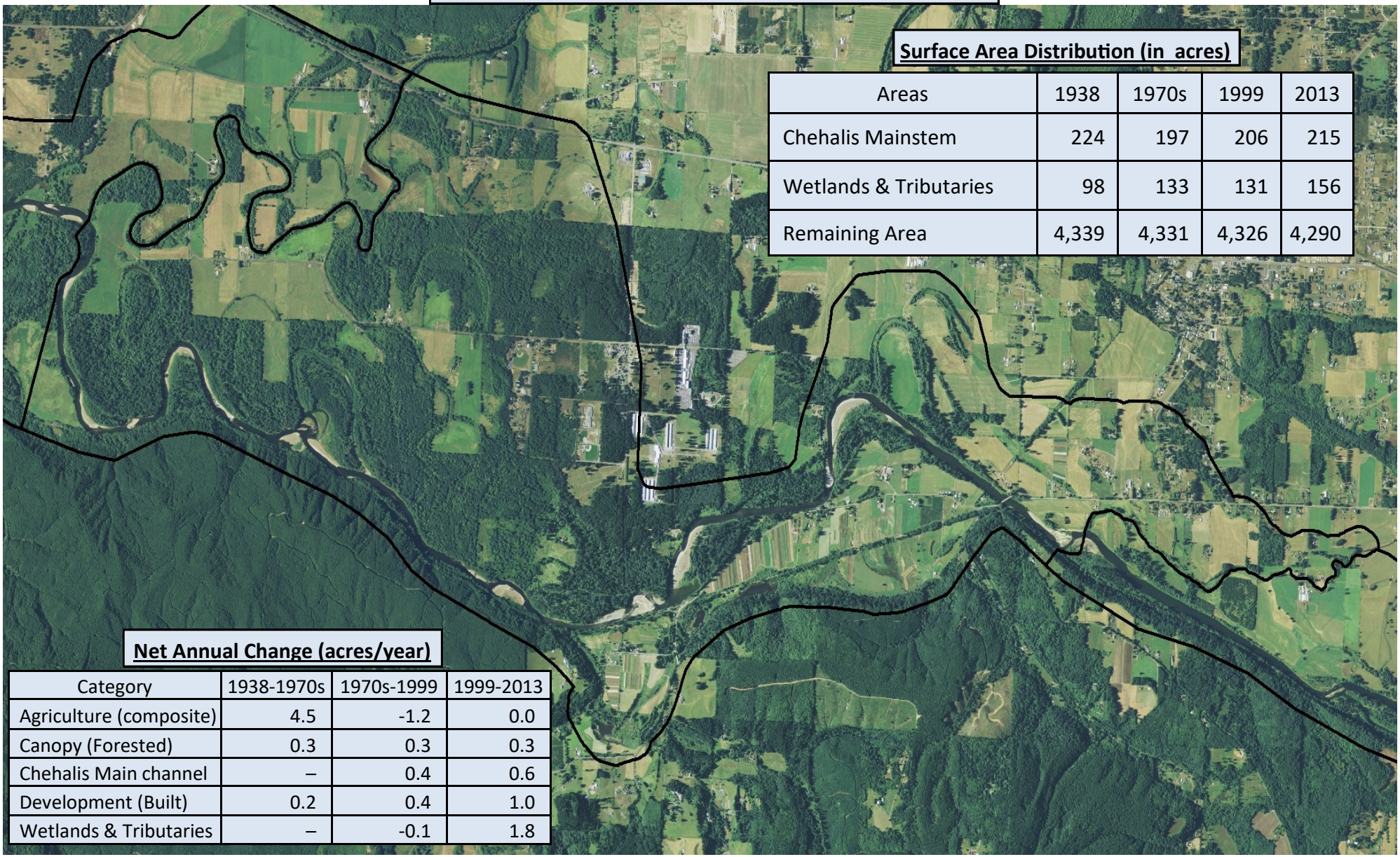
Losses (in acres)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture	65.4	105.9	127.3
Canopy	749.1	532.6	55.4
Development	13.9	7.3	1.9



Segment 5: Black River to Scatter Creek

Aerial Photograph based on 2013 NAIP



Surface Area Distribution (in acres)

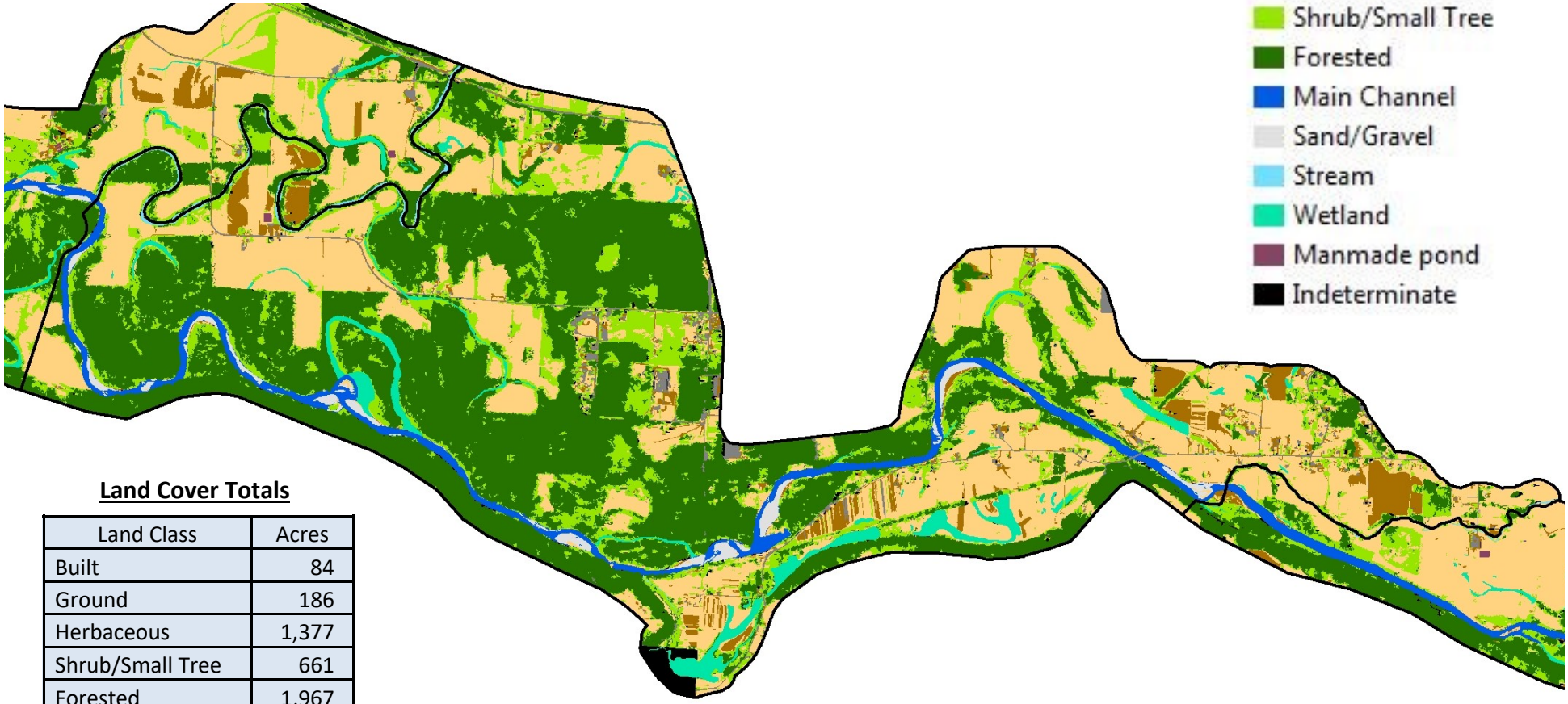
Areas	1938	1970s	1999	2013
Chehalis Mainstem	224	197	206	215
Wetlands & Tributaries	98	133	131	156
Remaining Area	4,339	4,331	4,326	4,290

Net Annual Change (acres/year)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture (composite)	4.5	-1.2	0.0
Canopy (Forested)	0.3	0.3	0.3
Chehalis Main channel	–	0.4	0.6
Development (Built)	0.2	0.4	1.0
Wetlands & Tributaries	–	-0.1	1.8

Segment 5: Black River to Scatter Creek

2013 Land Cover

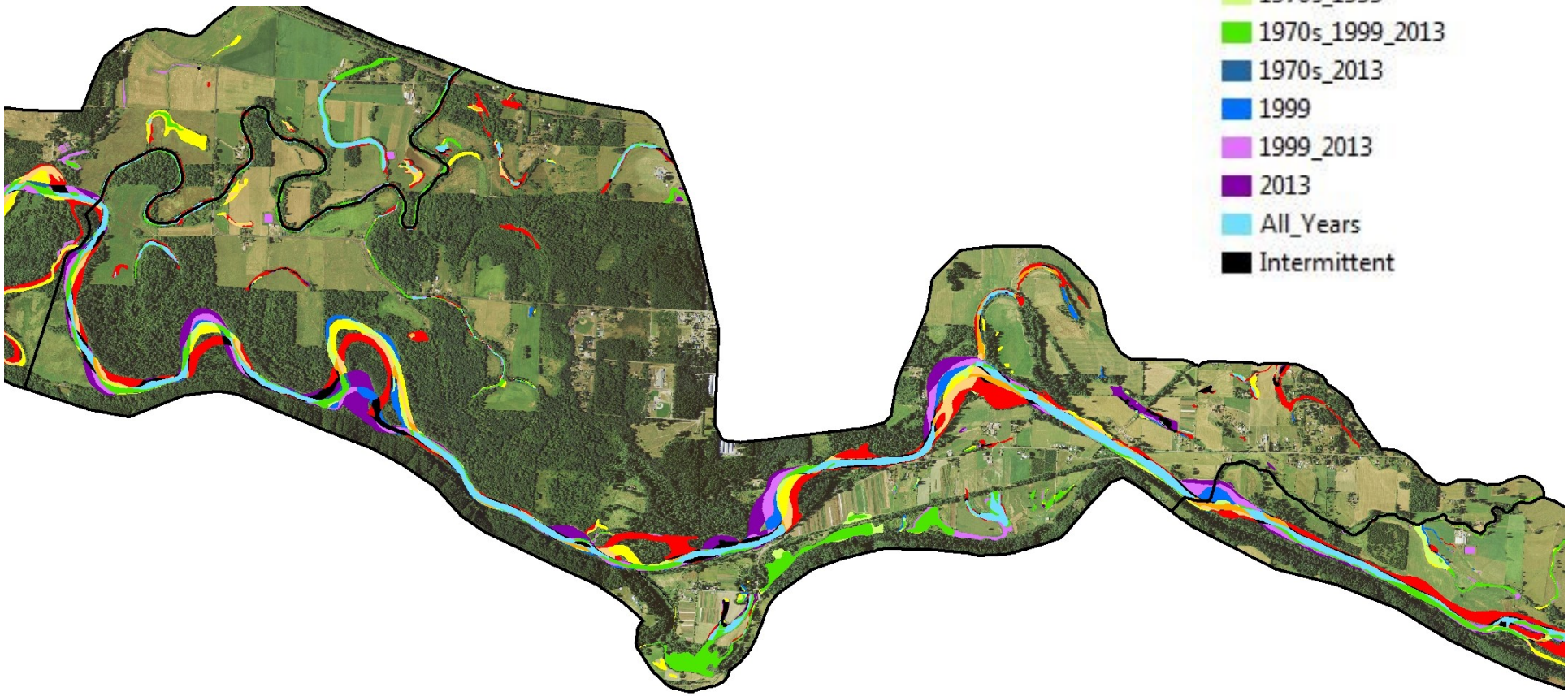


Land Cover Totals

Land Class	Acres
Built	84
Ground	186
Herbaceous	1,377
Shrub/Small Tree	661
Forested	1,967
Main Channel	144
Sand/Gravel	49
Stream	27
Wetland	128
Manmade pond	1
Indeterminate	36
Total	4,660

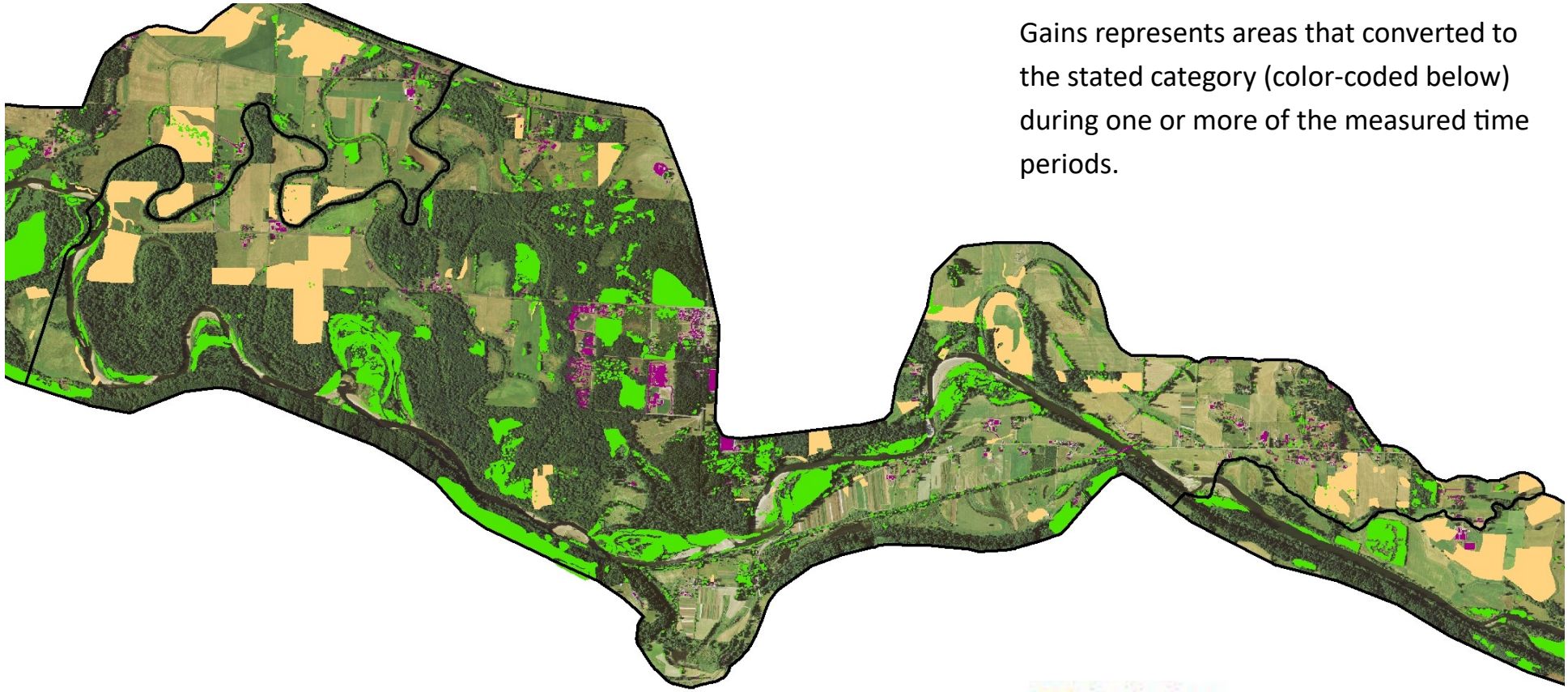
Segment 5: Black River to Scatter Creek

Water Surface by Years Visible



Segment 5: Black River to Scatter Creek

Land Cover Gains



Gains represents areas that converted to the stated category (color-coded below) during one or more of the measured time periods.

Gains (in acres)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture	214.2	15.1	0
Canopy	185.1	161.6	80.4
Development	13.3	17.5	14.6

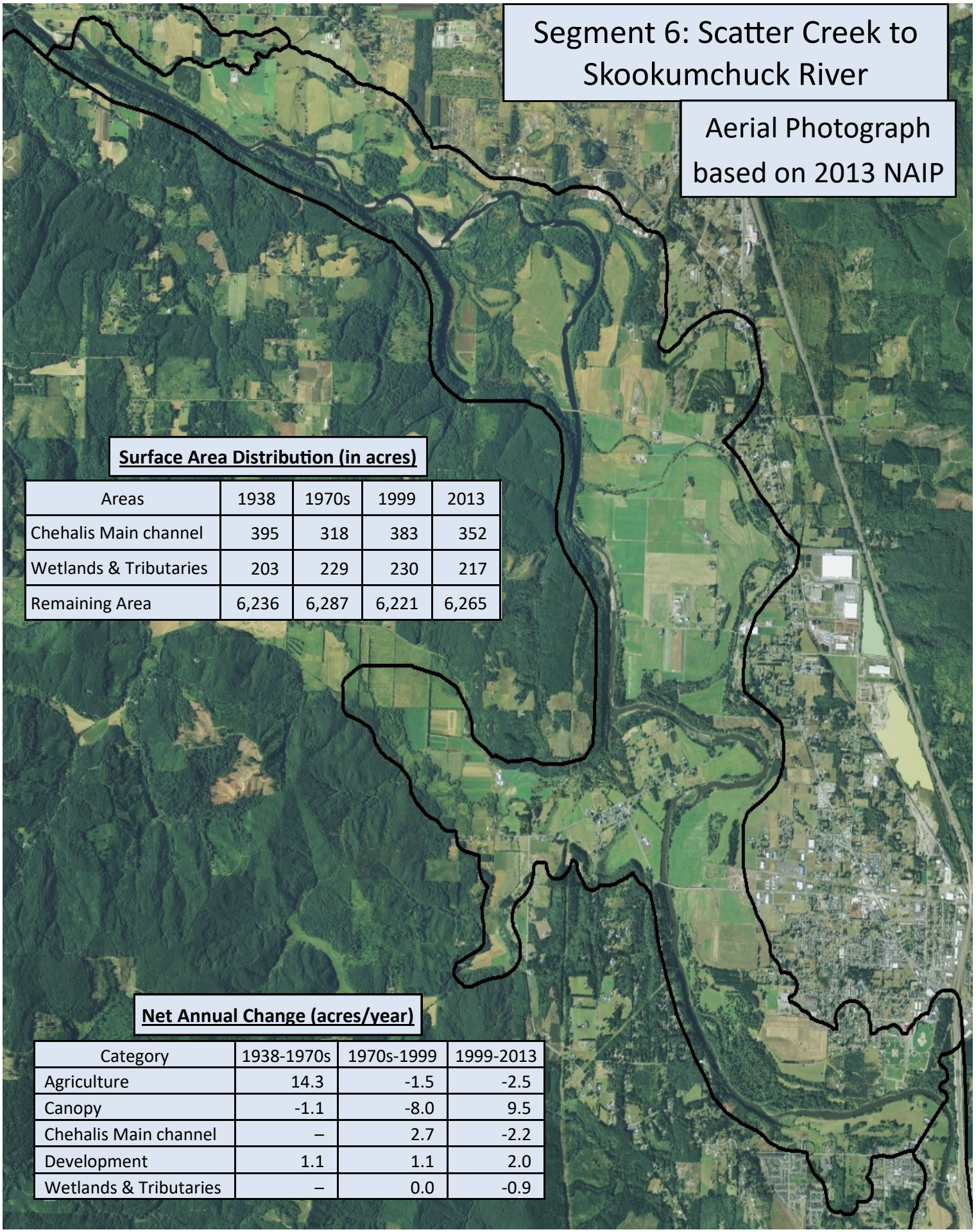
Segment 5: Black River to Scatter Creek

Land Cover Losses

Losses represent areas that converted from the stated category (color-coded below) to another category during one or more of the measured time periods.

Losses (in acres)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture	47.5	45.1	12.4
Canopy	172.4	154.0	76.9
Development	6.2	7.0	1.2

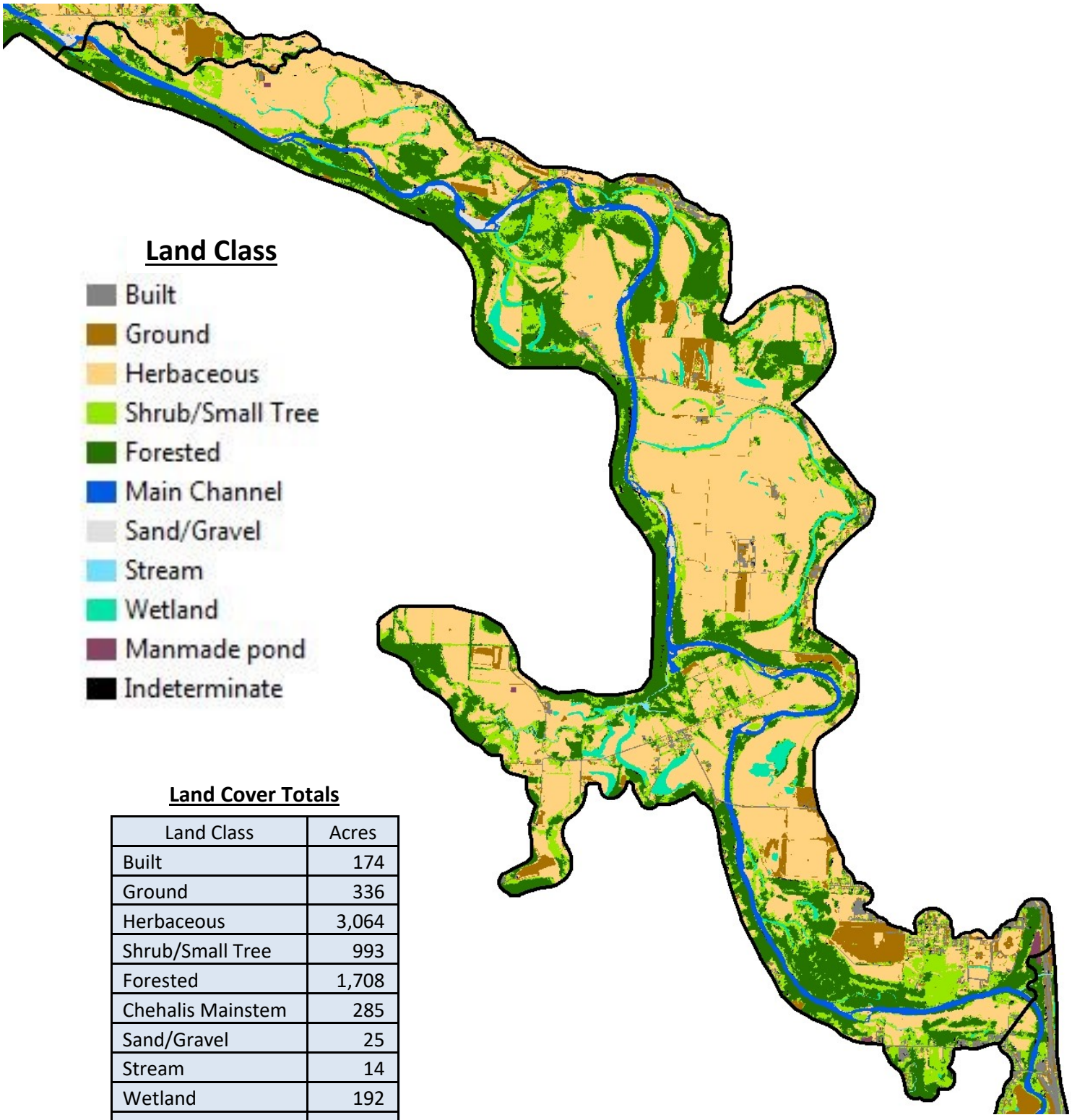


Surface Area Distribution (in acres)

Areas	1938	1970s	1999	2013
Chehalis Main channel	395	318	383	352
Wetlands & Tributaries	203	229	230	217
Remaining Area	6,236	6,287	6,221	6,265

Net Annual Change (acres/year)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture	14.3	-1.5	-2.5
Canopy	-1.1	-8.0	9.5
Chehalis Main channel	–	2.7	-2.2
Development	1.1	1.1	2.0
Wetlands & Tributaries	–	0.0	-0.9

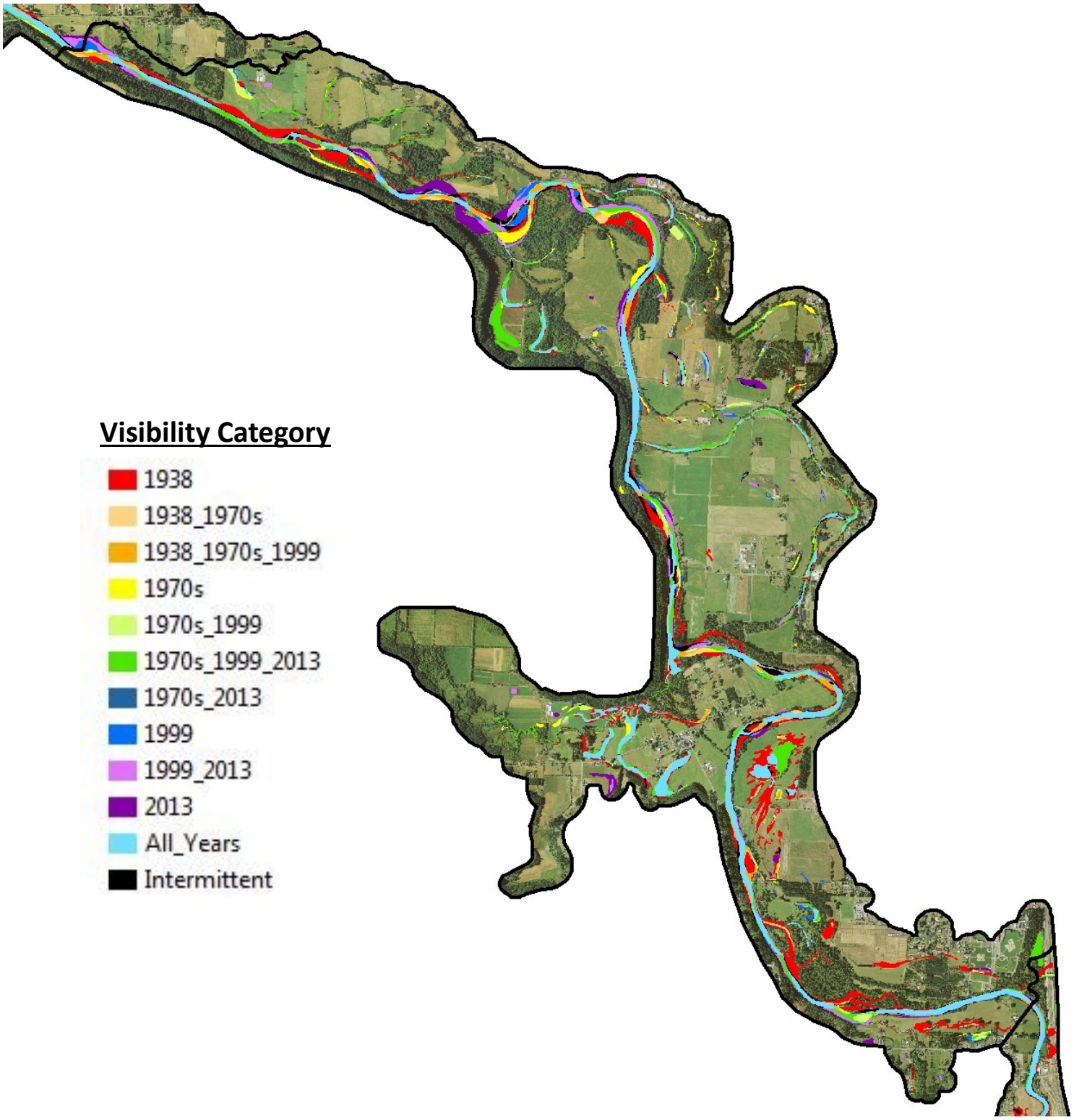


Land Cover Totals

Land Class	Acres
Built	174
Ground	336
Herbaceous	3,064
Shrub/Small Tree	993
Forested	1,708
Chehalis Mainstem	285
Sand/Gravel	25
Stream	14
Wetland	192
Manmade pond	11
Indeterminate	29
Total	6,831

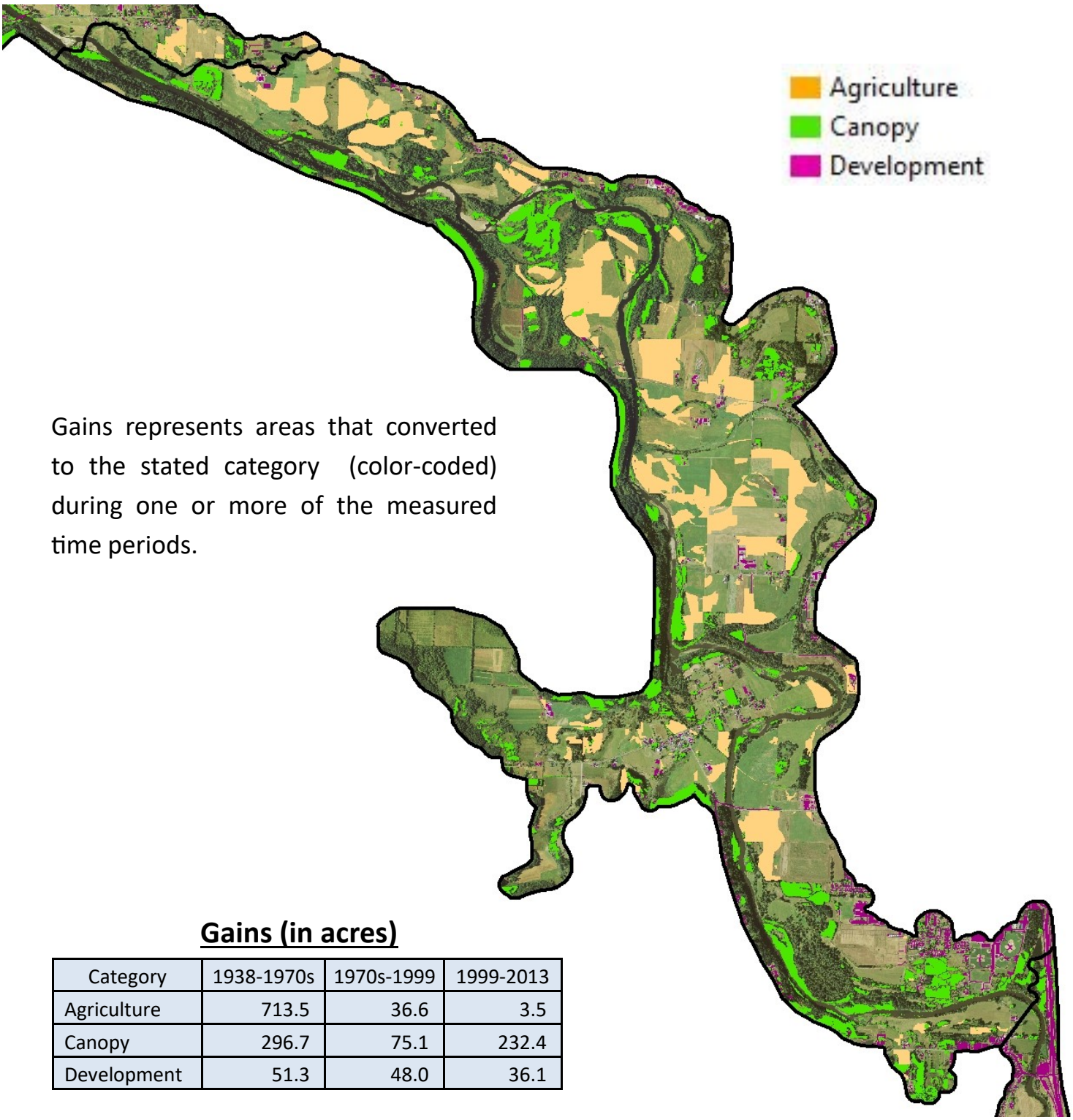
2013 Land Cover

Segment 6: Scatter Creek to Skookumchuck River



Water Surface by Years Visible

Segment 6: Scatter Creek to Skookumchuck River



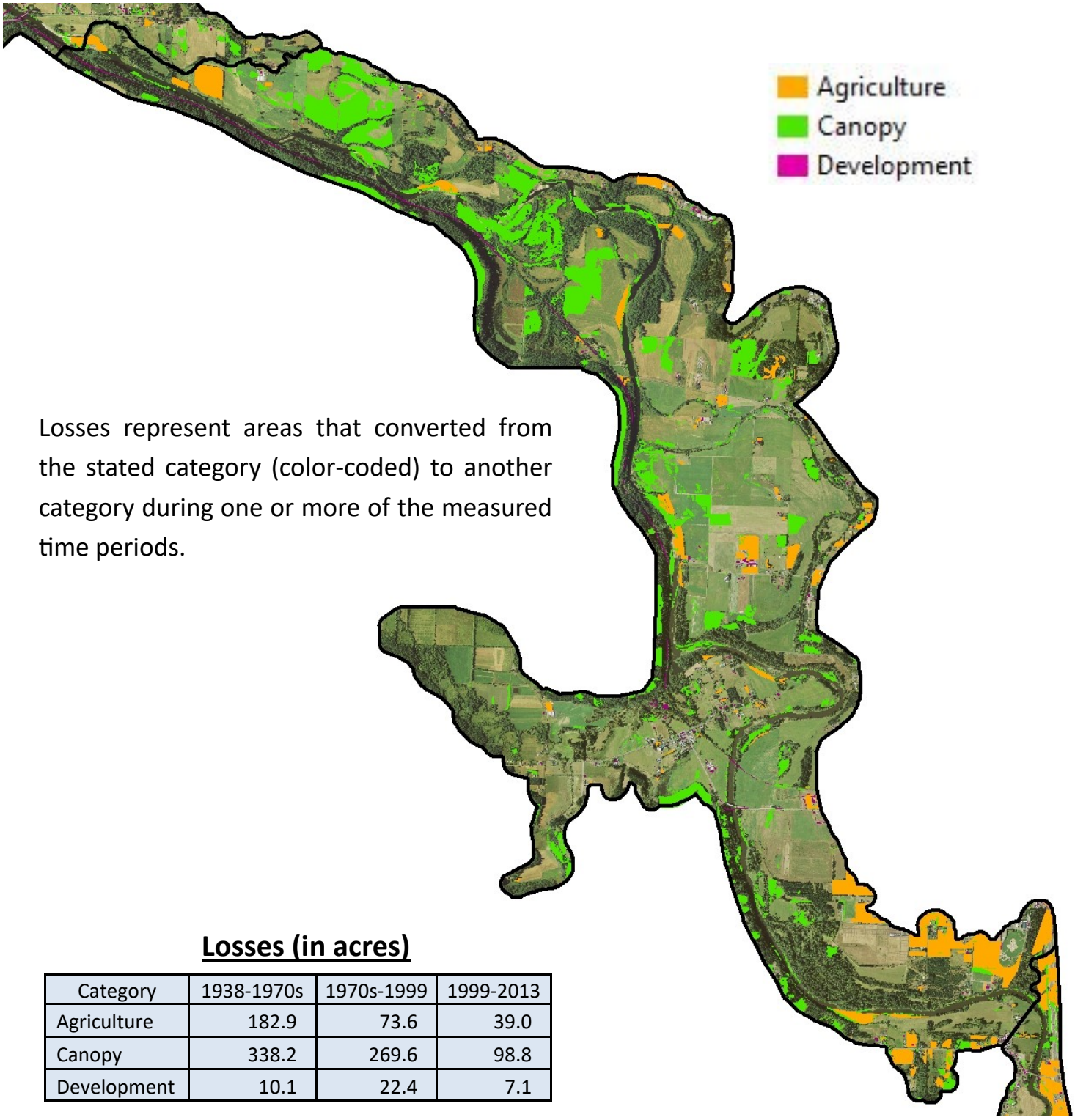
Gains represents areas that converted to the stated category (color-coded) during one or more of the measured time periods.

Gains (in acres)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture	713.5	36.6	3.5
Canopy	296.7	75.1	232.4
Development	51.3	48.0	36.1

Land Cover Gains

Segment 6: Scatter Creek to Skookumchuck River



Losses represent areas that converted from the stated category (color-coded) to another category during one or more of the measured time periods.

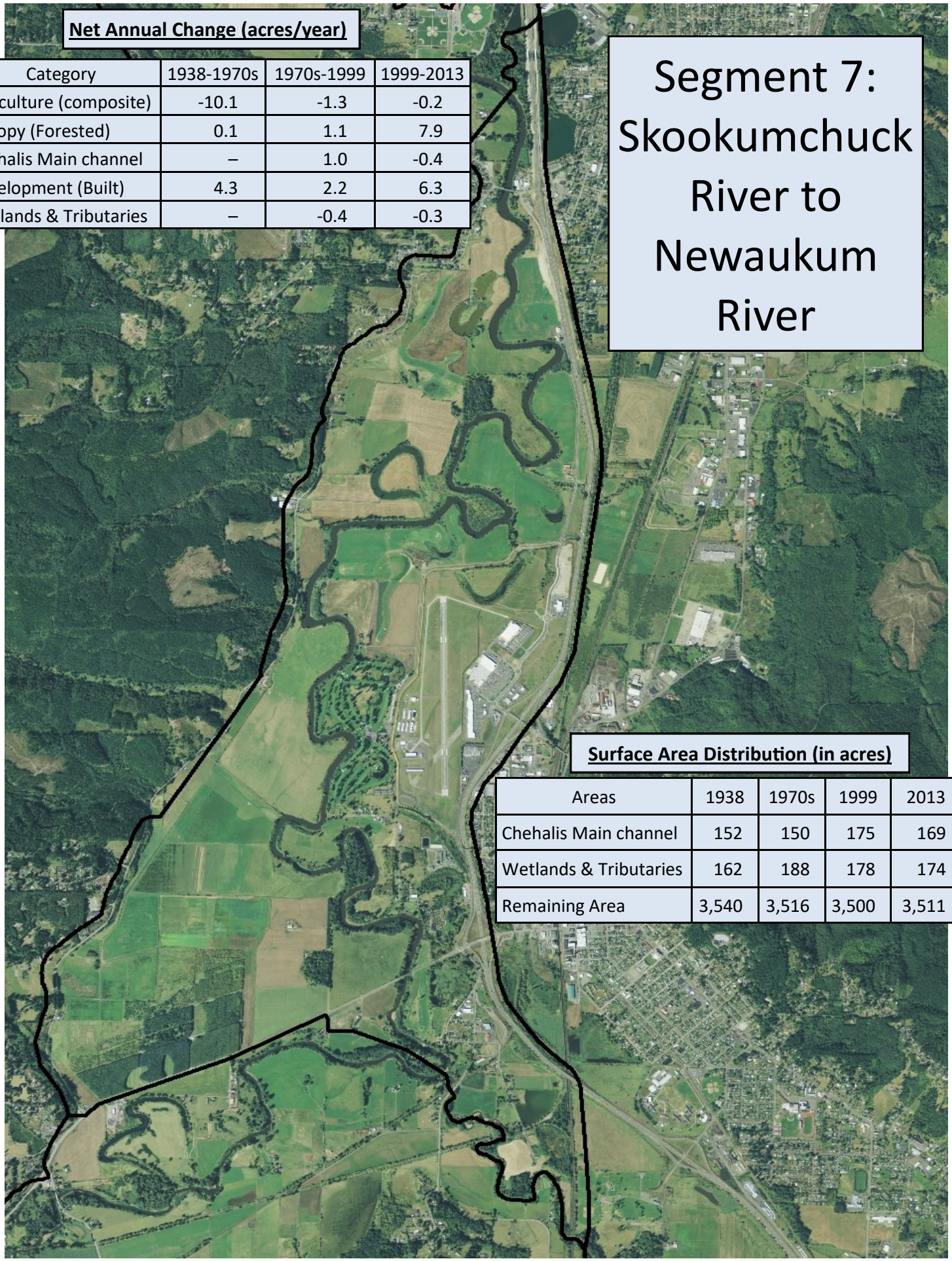
Losses (in acres)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture	182.9	73.6	39.0
Canopy	338.2	269.6	98.8
Development	10.1	22.4	7.1

Land Cover Losses

Segment 6: Scatter Creek to Skookumchuck River

Segment 7: Skookumchuck River to Newaukum River



Net Annual Change (acres/year)

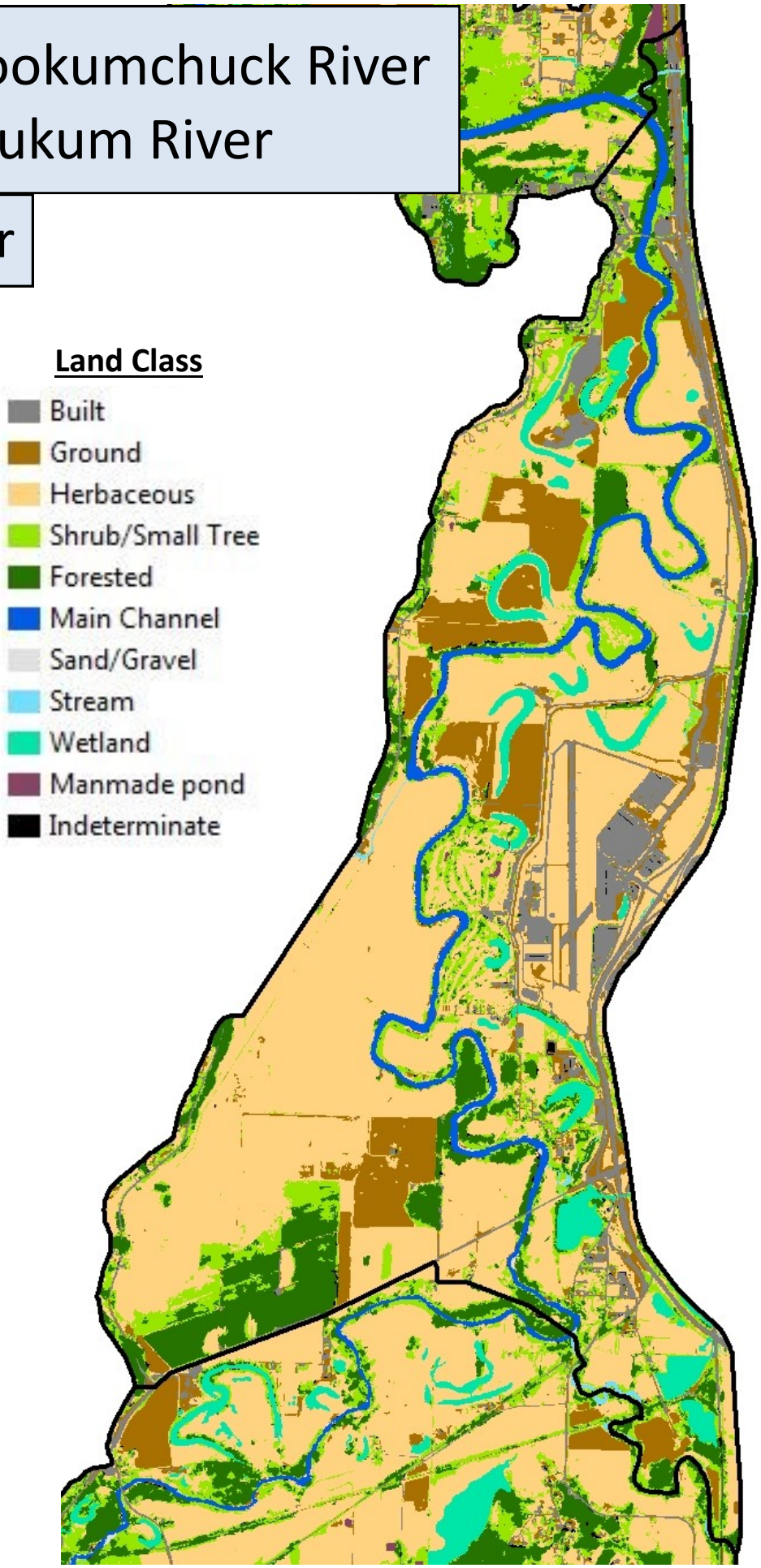
Category	1938-1970s	1970s-1999	1999-2013
Agriculture (composite)	-10.1	-1.3	-0.2
Canopy (Forested)	0.1	1.1	7.9
Chehalis Main channel	–	1.0	-0.4
Development (Built)	4.3	2.2	6.3
Wetlands & Tributaries	–	-0.4	-0.3

Surface Area Distribution (in acres)

Areas	1938	1970s	1999	2013
Chehalis Main channel	152	150	175	169
Wetlands & Tributaries	162	188	178	174
Remaining Area	3,540	3,516	3,500	3,511

Segment 7: Skookumchuck River to Newaukum River

2013 Land Cover

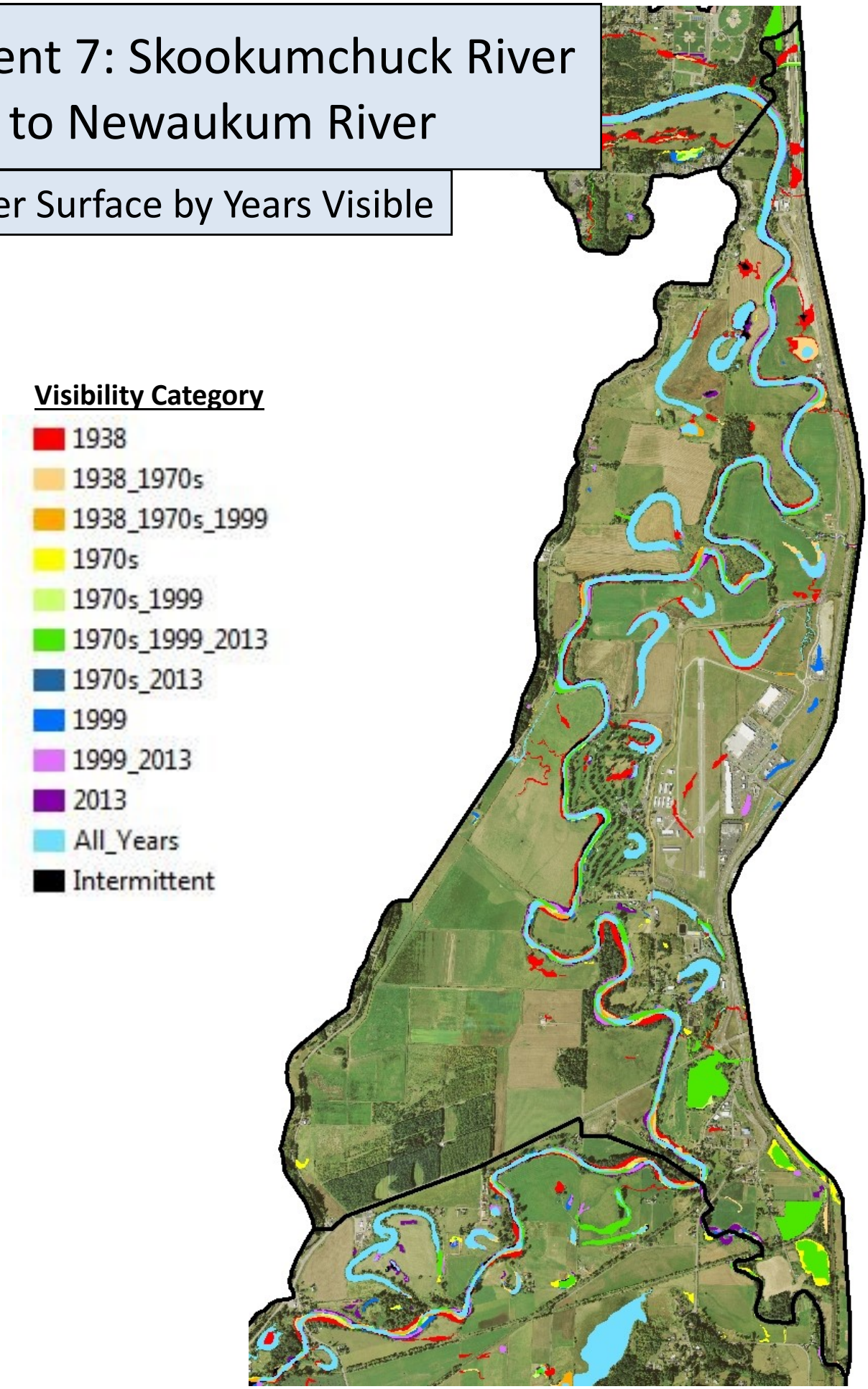


Land Cover Totals

Land Class	Acres
Built	349
Ground	471
Herbaceous	1,889
Shrub/Small Tree	426
Forested	380
Main Channel	146
Sand/Gravel	3
Stream	14
Wetland	156
Manmade pond	4
Indeterminate	14
Total	3,852

Segment 7: Skookumchuck River to Newaukum River

Water Surface by Years Visible



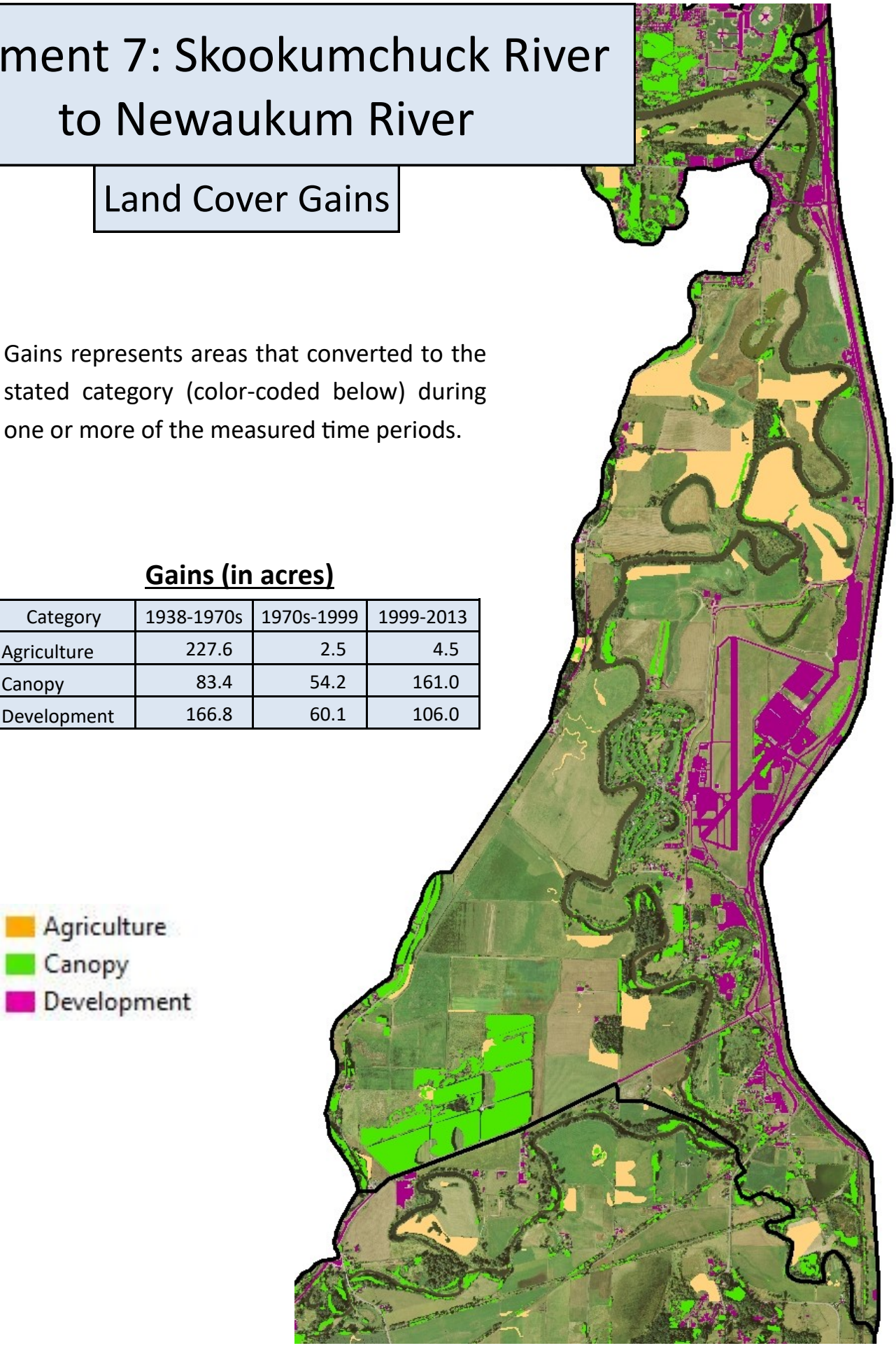
Segment 7: Skookumchuck River to Newaukum River

Land Cover Gains

Gains represents areas that converted to the stated category (color-coded below) during one or more of the measured time periods.

Gains (in acres)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture	227.6	2.5	4.5
Canopy	83.4	54.2	161.0
Development	166.8	60.1	106.0



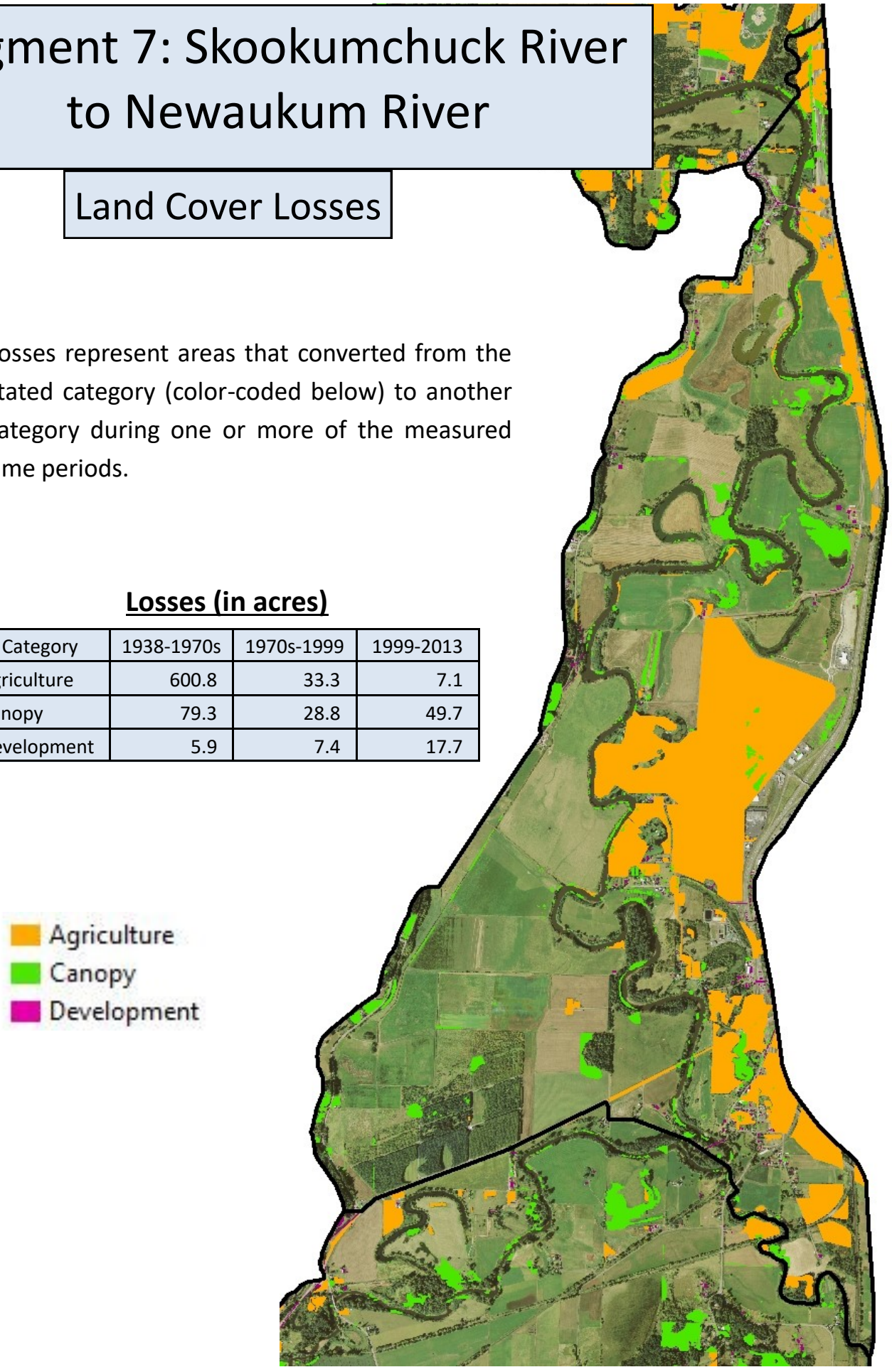
Segment 7: Skookumchuck River to Newaukum River

Land Cover Losses

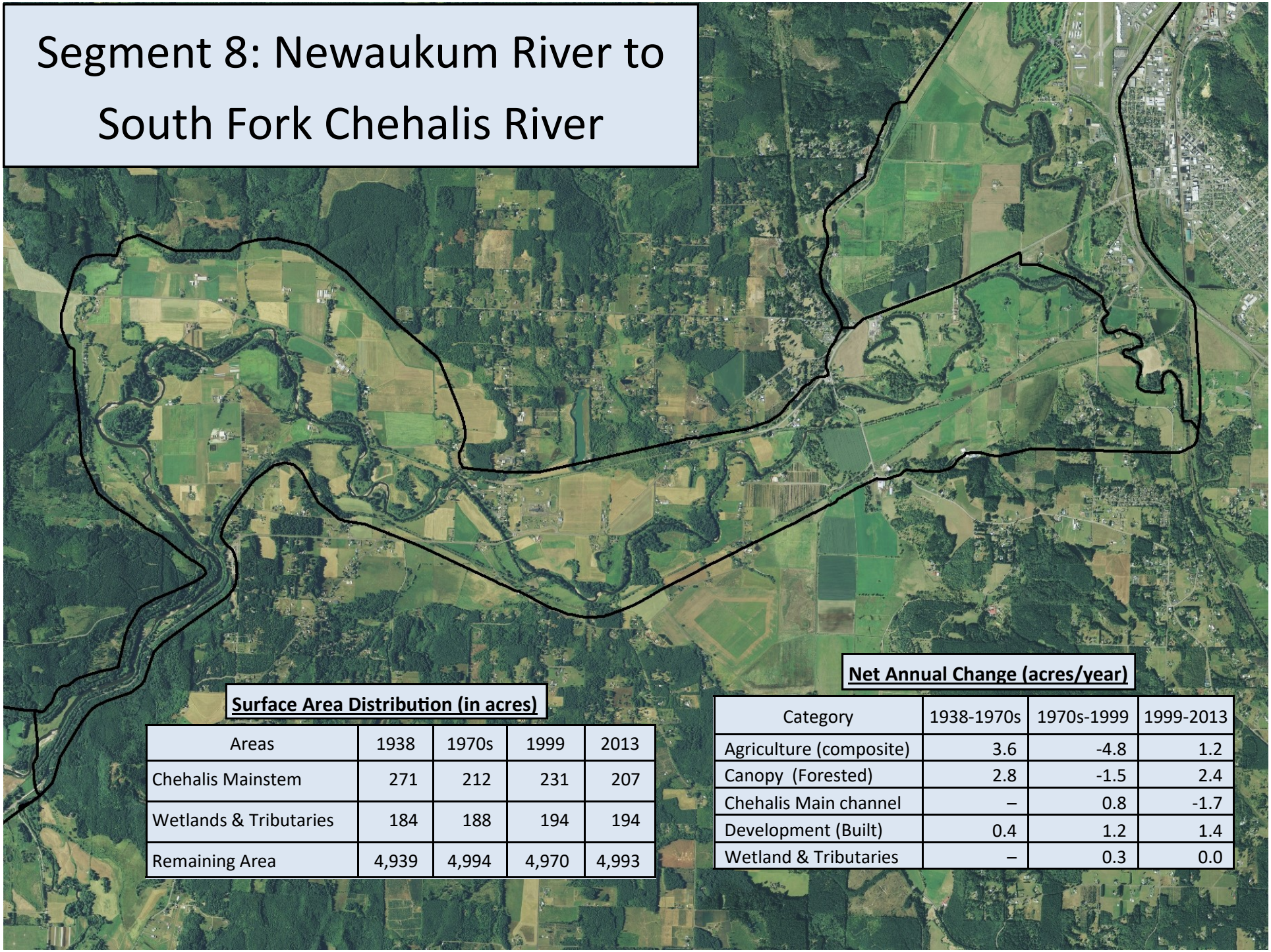
Losses represent areas that converted from the stated category (color-coded below) to another category during one or more of the measured time periods.

Losses (in acres)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture	600.8	33.3	7.1
Canopy	79.3	28.8	49.7
Development	5.9	7.4	17.7



Segment 8: Newaukum River to South Fork Chehalis River



Surface Area Distribution (in acres)

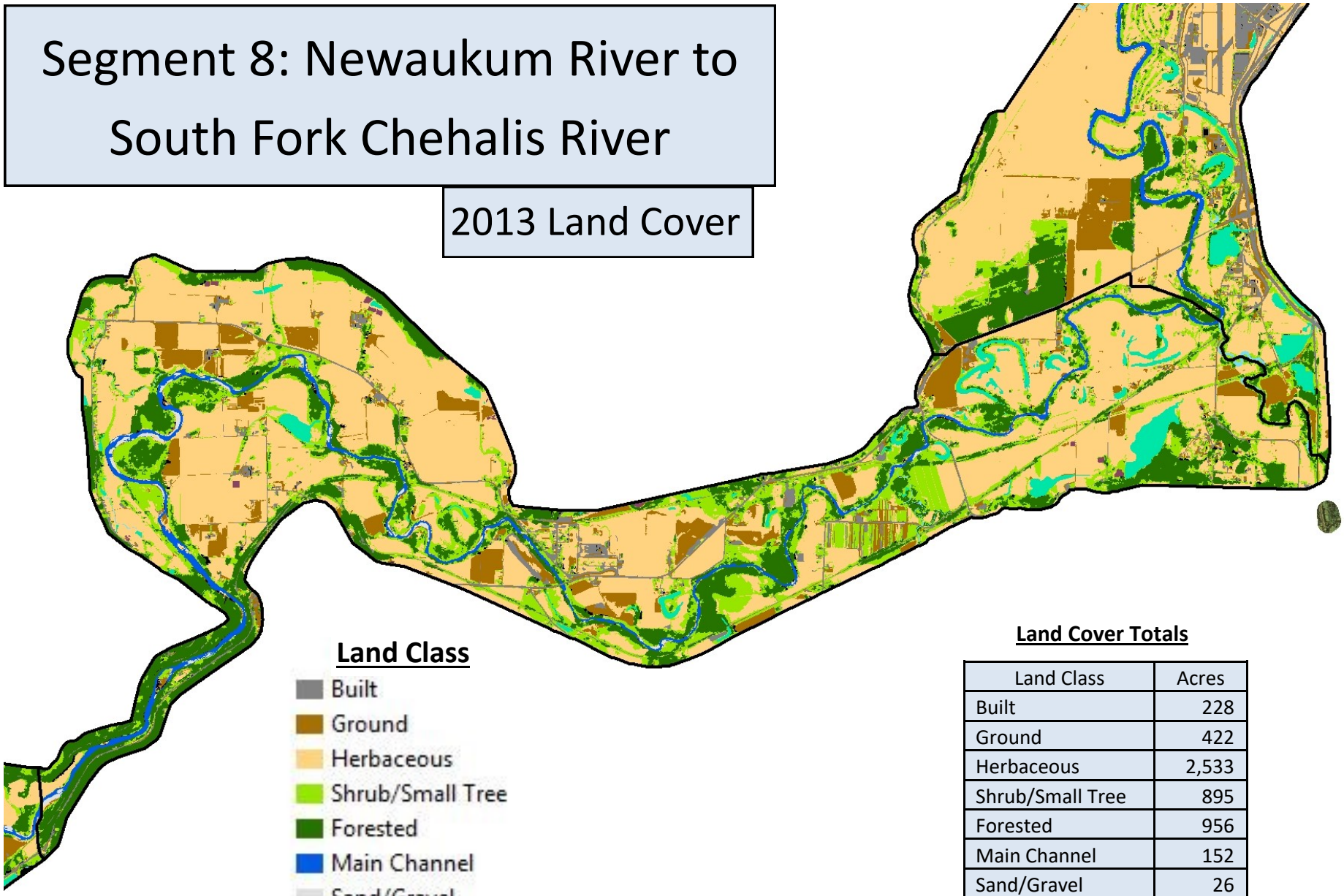
Areas	1938	1970s	1999	2013
Chehalis Mainstem	271	212	231	207
Wetlands & Tributaries	184	188	194	194
Remaining Area	4,939	4,994	4,970	4,993

Net Annual Change (acres/year)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture (composite)	3.6	-4.8	1.2
Canopy (Forested)	2.8	-1.5	2.4
Chehalis Main channel	–	0.8	-1.7
Development (Built)	0.4	1.2	1.4
Wetland & Tributaries	–	0.3	0.0

Segment 8: Newaukum River to South Fork Chehalis River

2013 Land Cover

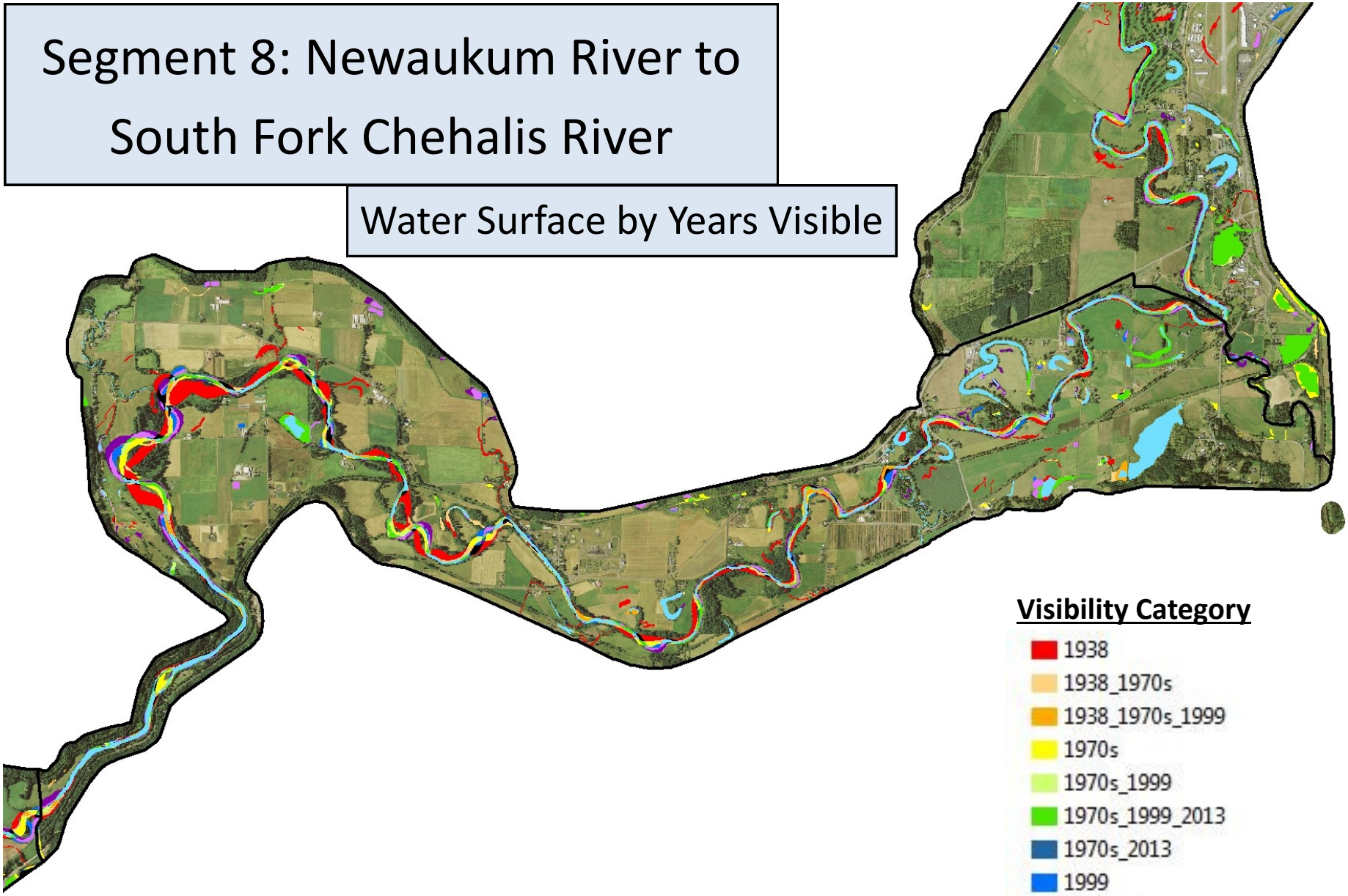


Land Cover Totals

Land Class	Acres
Built	228
Ground	422
Herbaceous	2,533
Shrub/Small Tree	895
Forested	956
Main Channel	152
Sand/Gravel	26
Stream	15
Wetland	131
Manmade pond	10
Indeterminate	25
Total	5,393

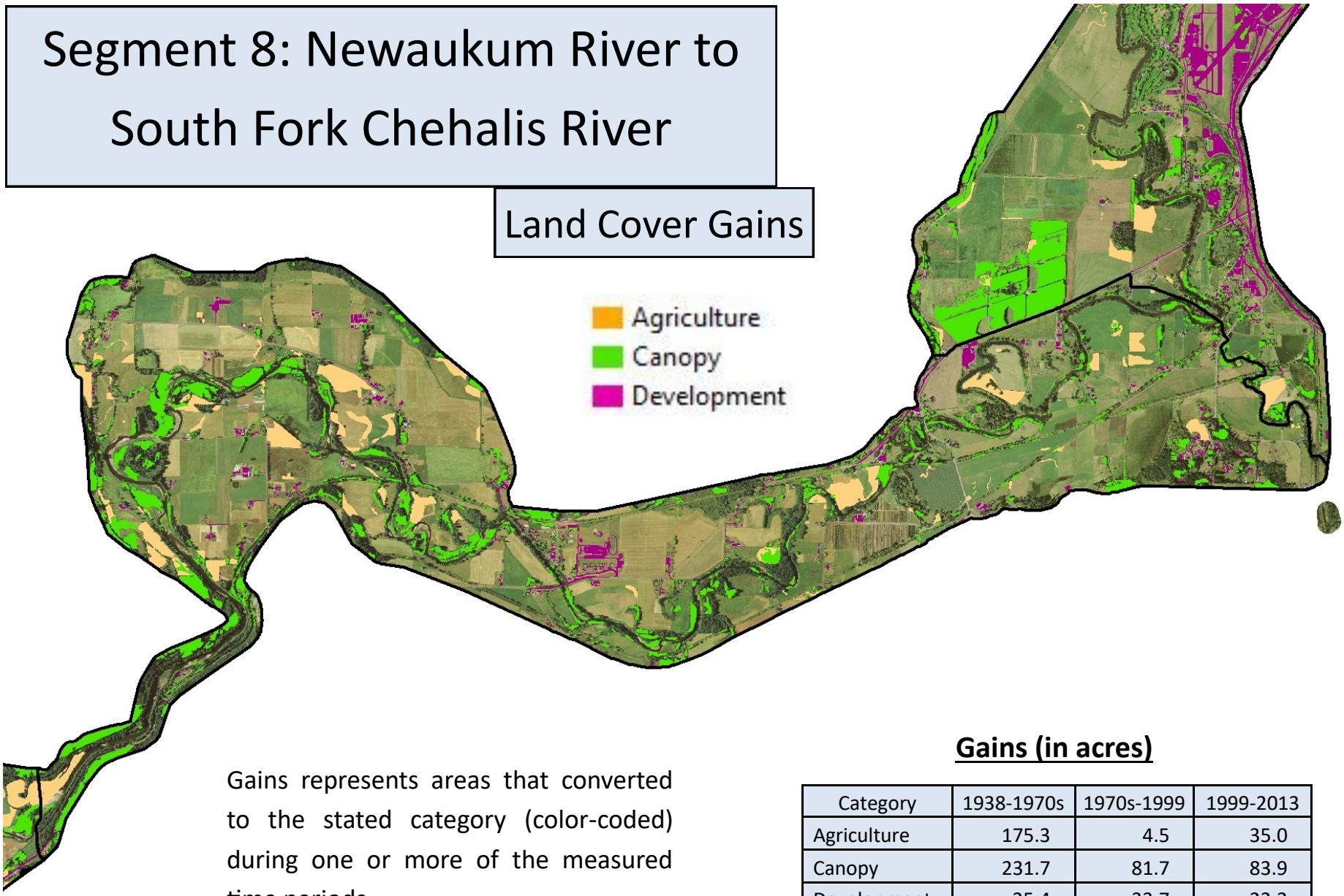
Segment 8: Newaukum River to South Fork Chehalis River

Water Surface by Years Visible



Segment 8: Newaukum River to South Fork Chehalis River

Land Cover Gains



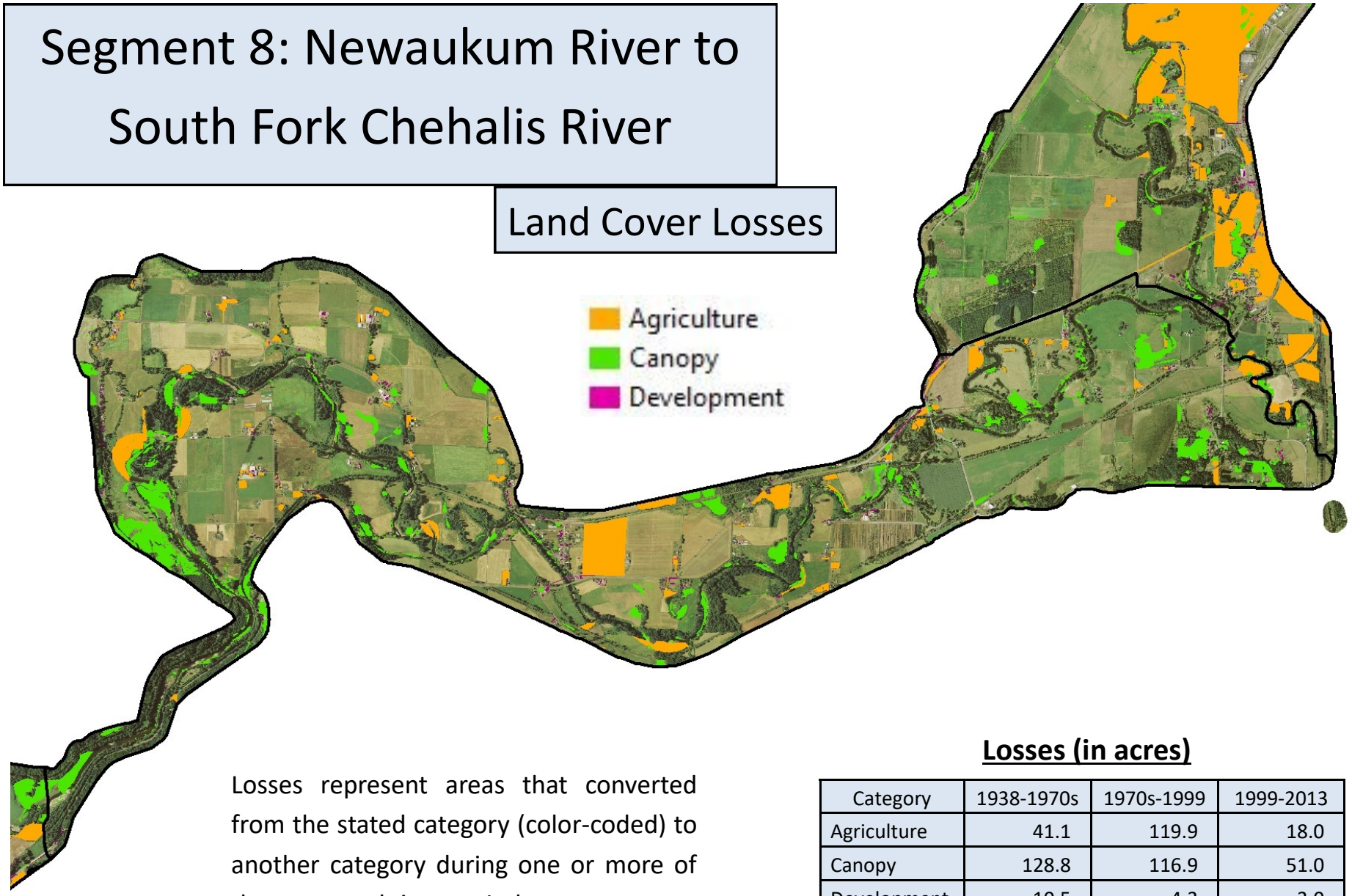
Gains represents areas that converted to the stated category (color-coded) during one or more of the measured time periods.

Gains (in acres)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture	175.3	4.5	35.0
Canopy	231.7	81.7	83.9
Development	25.4	33.7	23.2

Segment 8: Newaukum River to South Fork Chehalis River

Land Cover Losses

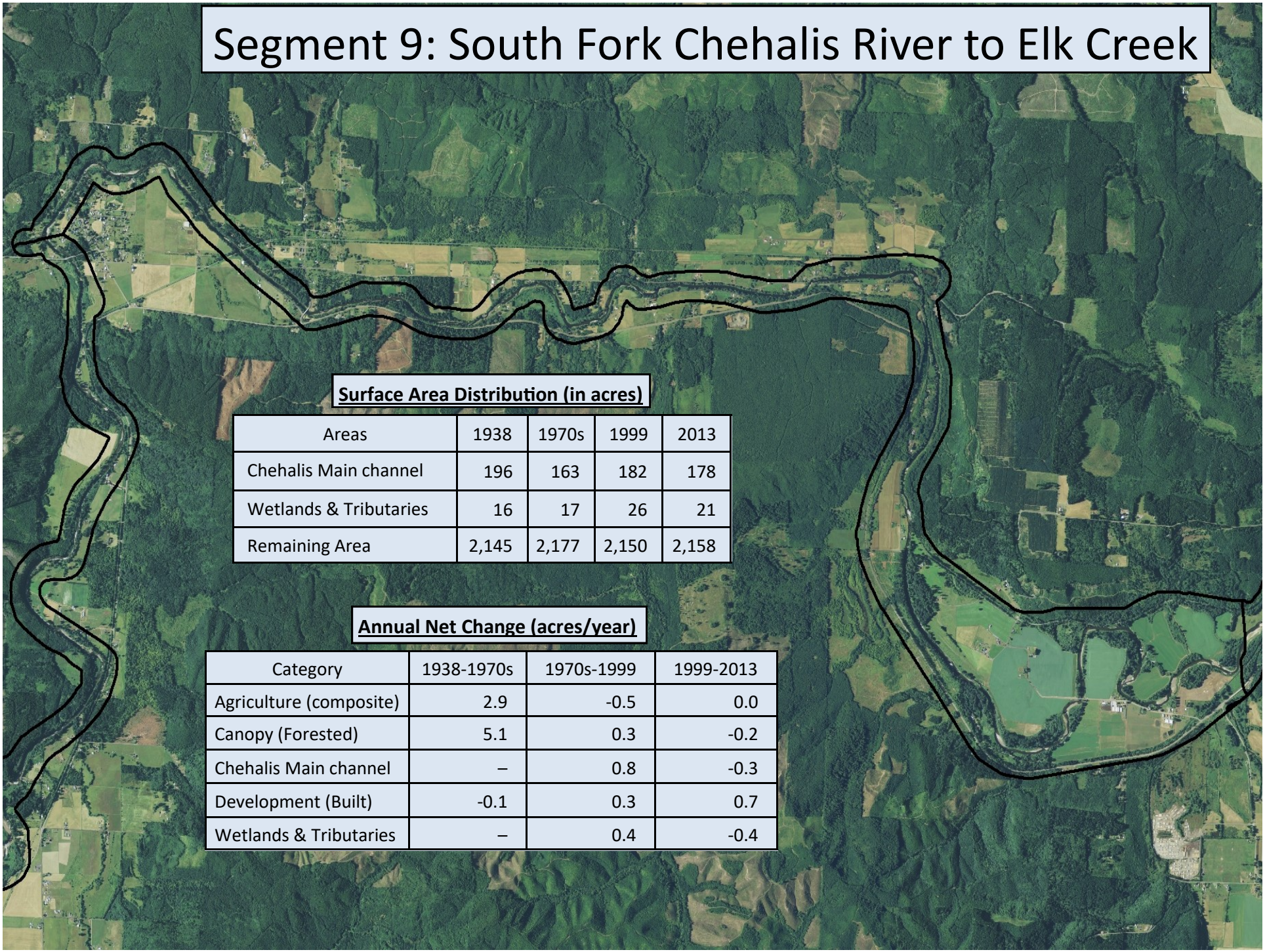


Losses represent areas that converted from the stated category (color-coded) to another category during one or more of the measured time periods.

Losses (in acres)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture	41.1	119.9	18.0
Canopy	128.8	116.9	51.0
Development	10.5	4.3	3.0

Segment 9: South Fork Chehalis River to Elk Creek



Surface Area Distribution (in acres)

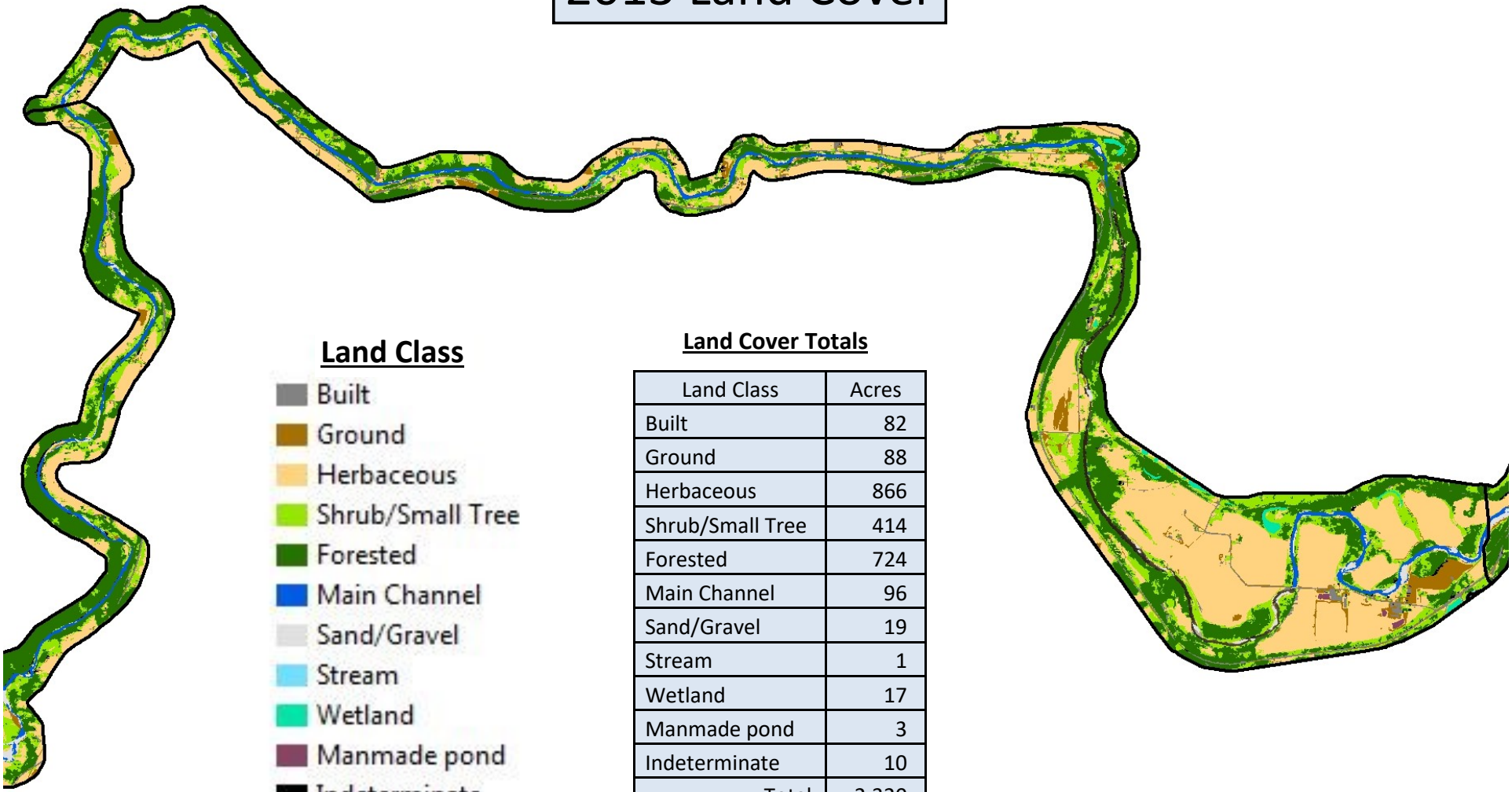
Areas	1938	1970s	1999	2013
Chehalis Main channel	196	163	182	178
Wetlands & Tributaries	16	17	26	21
Remaining Area	2,145	2,177	2,150	2,158

Annual Net Change (acres/year)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture (composite)	2.9	-0.5	0.0
Canopy (Forested)	5.1	0.3	-0.2
Chehalis Main channel	–	0.8	-0.3
Development (Built)	-0.1	0.3	0.7
Wetlands & Tributaries	–	0.4	-0.4

Segment 9: South Fork Chehalis River to Elk Creek

2013 Land Cover

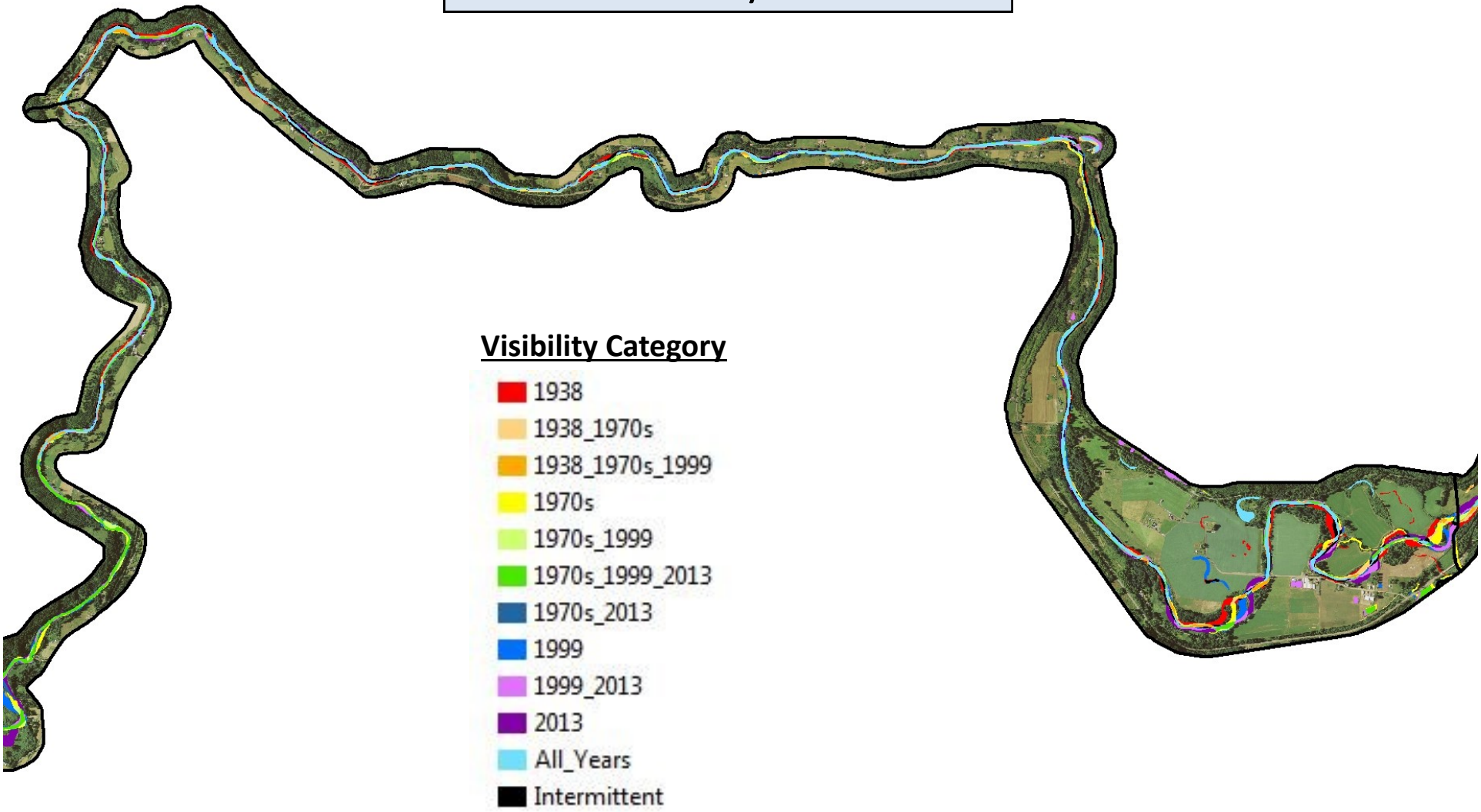


Land Cover Totals

Land Class	Acres
Built	82
Ground	88
Herbaceous	866
Shrub/Small Tree	414
Forested	724
Main Channel	96
Sand/Gravel	19
Stream	1
Wetland	17
Manmade pond	3
Indeterminate	10
Total	2,320

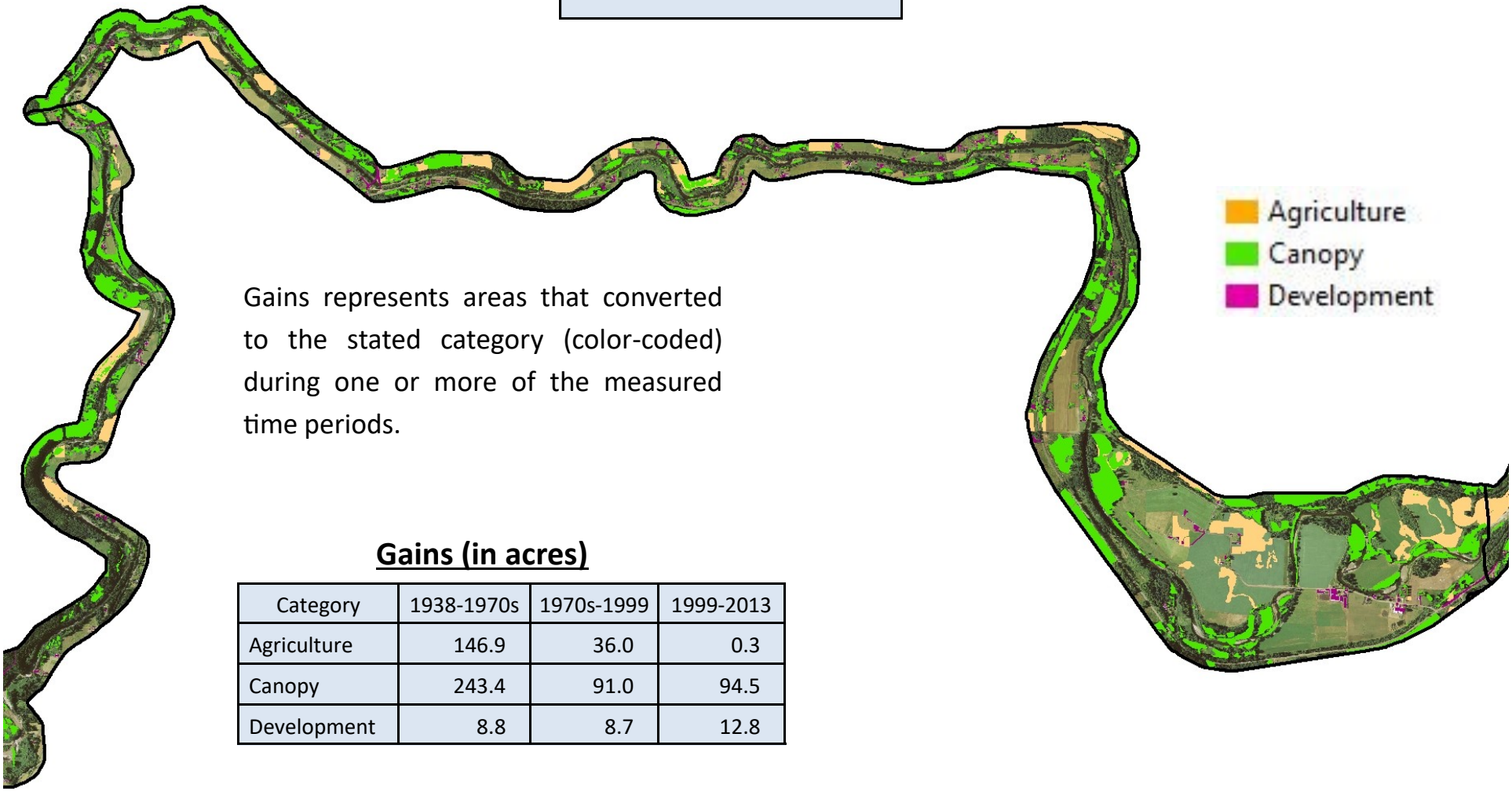
Segment 9: South Fork Chehalis River to Elk Creek

Water Surface by Years Visible



Segment 9: South Fork Chehalis River to Elk Creek

Land Cover Gains



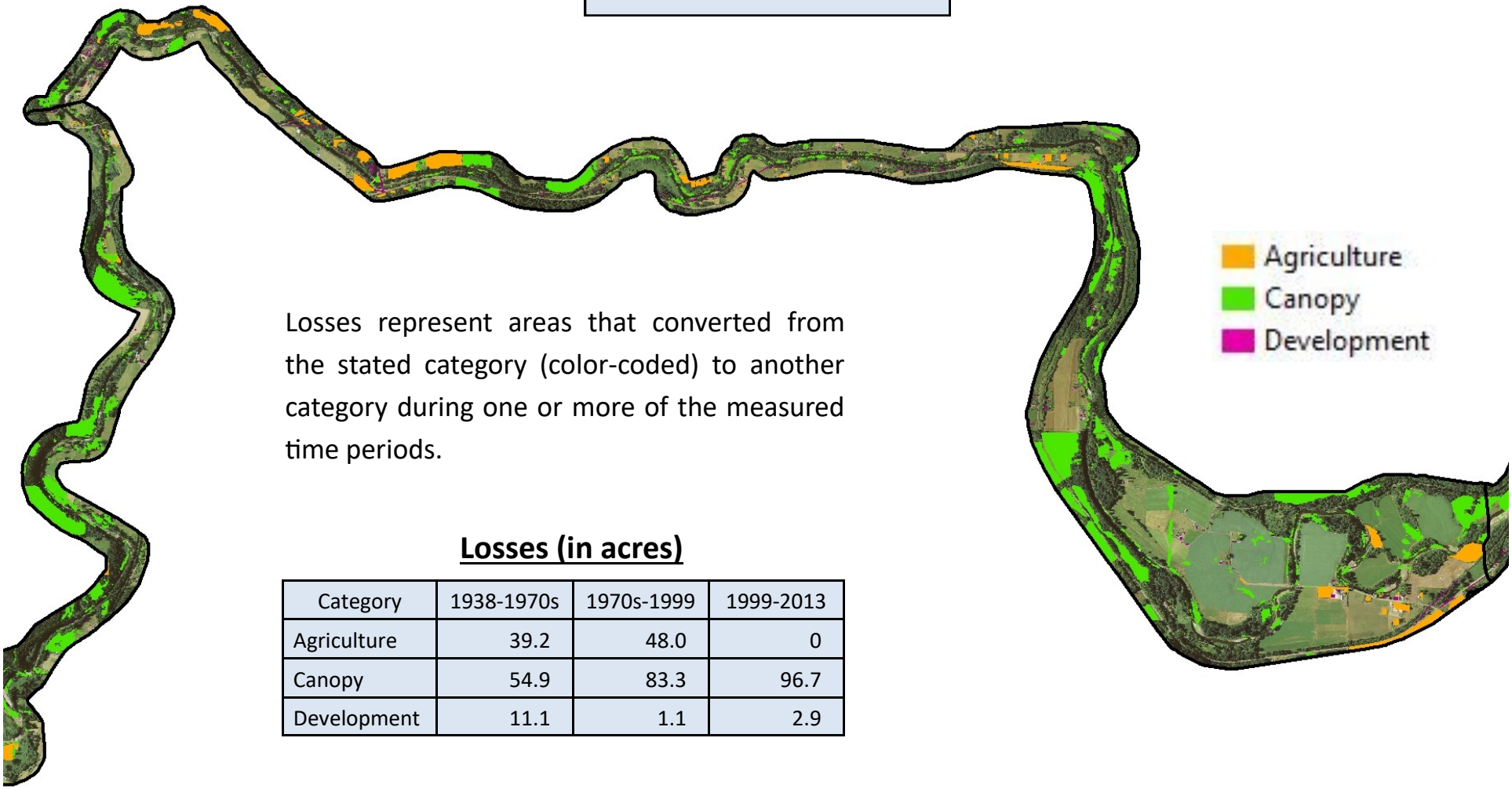
Gains represents areas that converted to the stated category (color-coded) during one or more of the measured time periods.

Gains (in acres)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture	146.9	36.0	0.3
Canopy	243.4	91.0	94.5
Development	8.8	8.7	12.8

Segment 9: South Fork Chehalis River to Elk Creek

Land Cover Losses

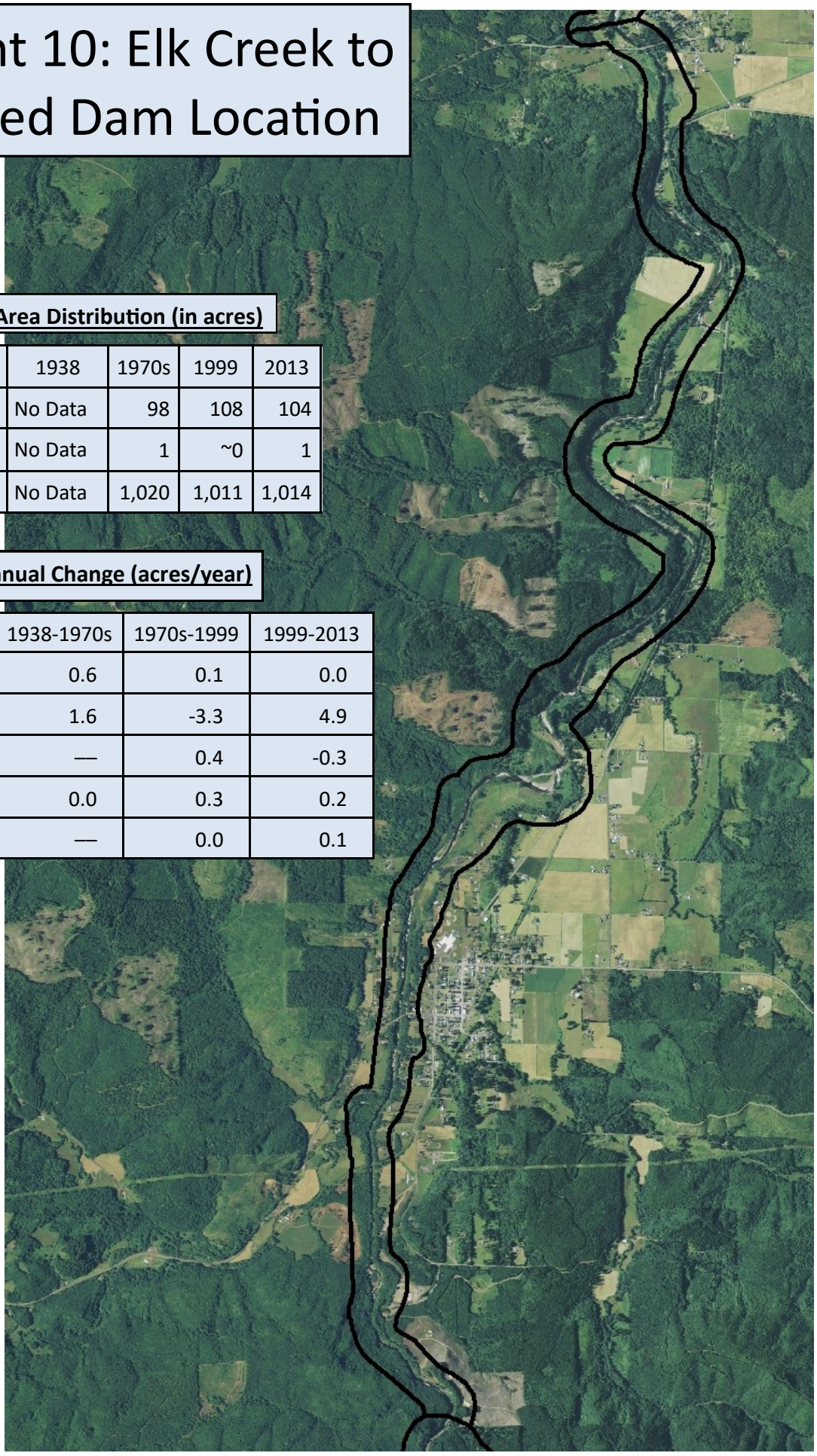


Losses represent areas that converted from the stated category (color-coded) to another category during one or more of the measured time periods.

Losses (in acres)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture	39.2	48.0	0
Canopy	54.9	83.3	96.7
Development	11.1	1.1	2.9

Segment 10: Elk Creek to Proposed Dam Location



Surface Area Distribution (in acres)

Areas	1938	1970s	1999	2013
Chehalis Mainstem	No Data	98	108	104
Wetlands & Tributaries	No Data	1	~0	1
Remaining Area	No Data	1,020	1,011	1,014

Net Annual Change (acres/year)

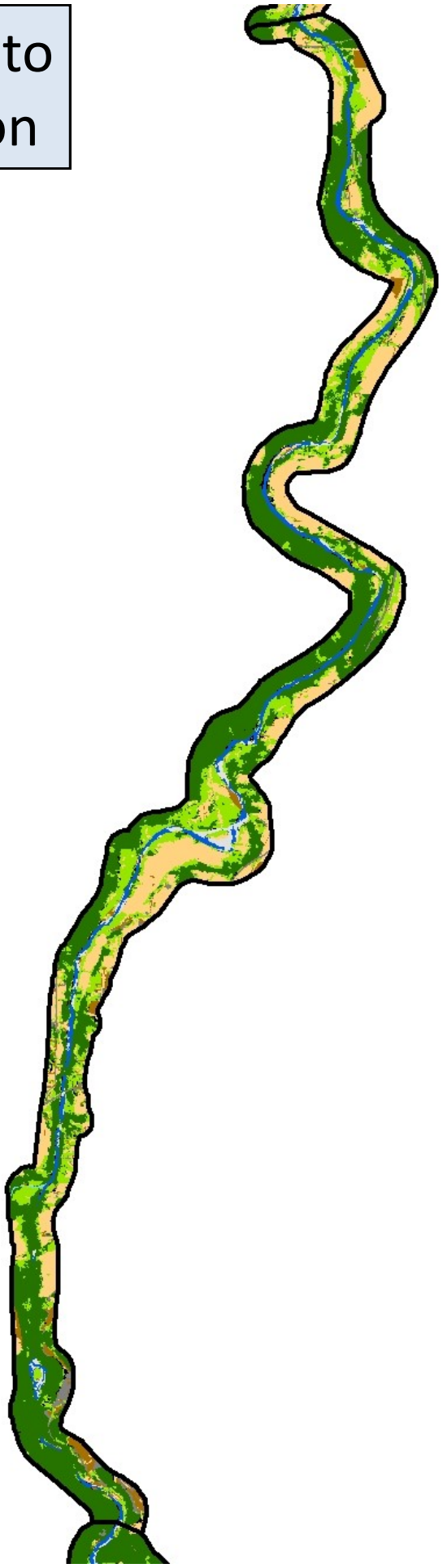
Category	1938-1970s	1970s-1999	1999-2013
Agriculture	0.6	0.1	0.0
Canopy	1.6	-3.3	4.9
Chehalis Main channel	—	0.4	-0.3
Development	0.0	0.3	0.2
Wetlands & Tributaries	—	0.0	0.1

Segment 10: Elk Creek to Proposed Dam Location

2013 Land Cover

Land Class

- Built
- Ground
- Herbaceous
- Shrub/Small Tree
- Forested
- Main Channel
- Sand/Gravel
- Stream
- Wetland
- Manmade pond
- Indeterminate

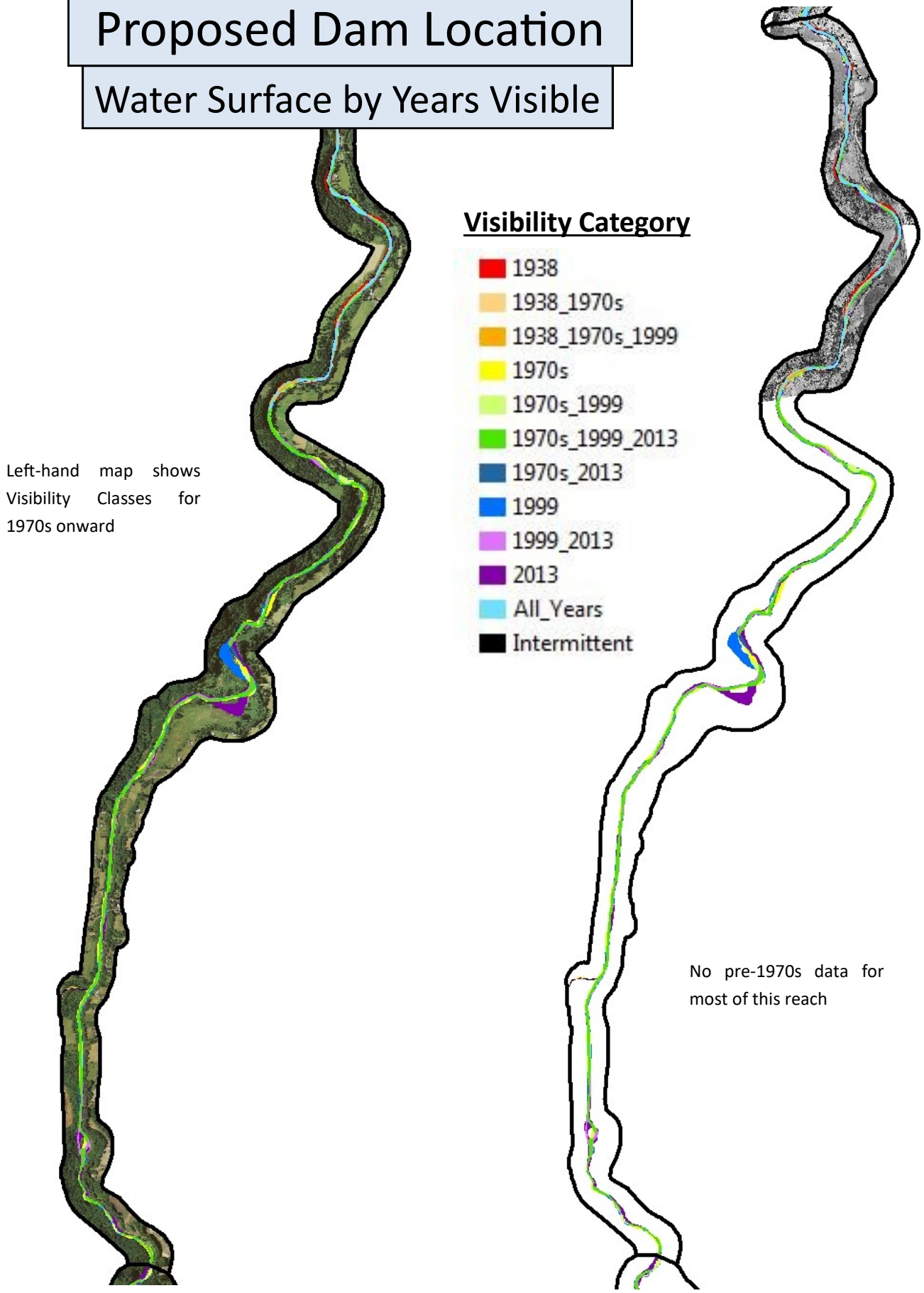


Land Cover Totals

Land Class	Acres
Built	27
Ground	37
Herbaceous	257
Shrub/Small Tree	200
Forested	509
Main Channel	61
Sand/Gravel	18
Stream	1
Indeterminate	8
Total	1,118

Segment 10: Elk Creek to Proposed Dam Location

Water Surface by Years Visible



Left-hand map shows Visibility Classes for 1970s onward

No pre-1970s data for most of this reach

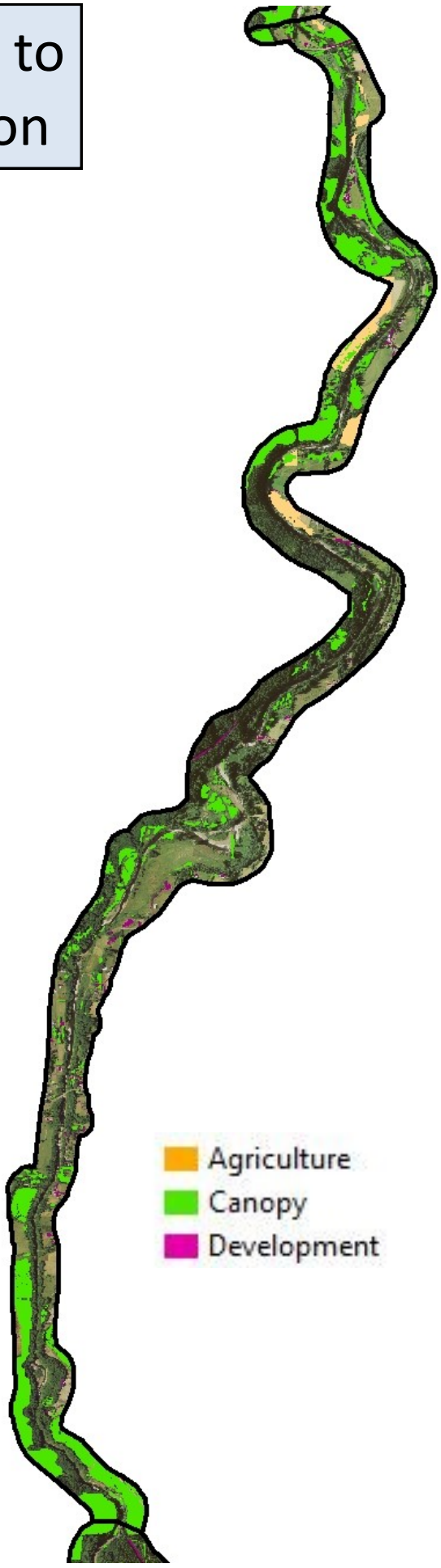
Segment 10: Elk Creek to Proposed Dam Location

Land Cover Gains

Gains represents areas that converted to the stated category (color-coded) during one or more of the measured time periods.

Gains (in acres)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture	24.9	7.0	0
Canopy	60.4	48.6	112.7
Development	0.8	7.0	3.2



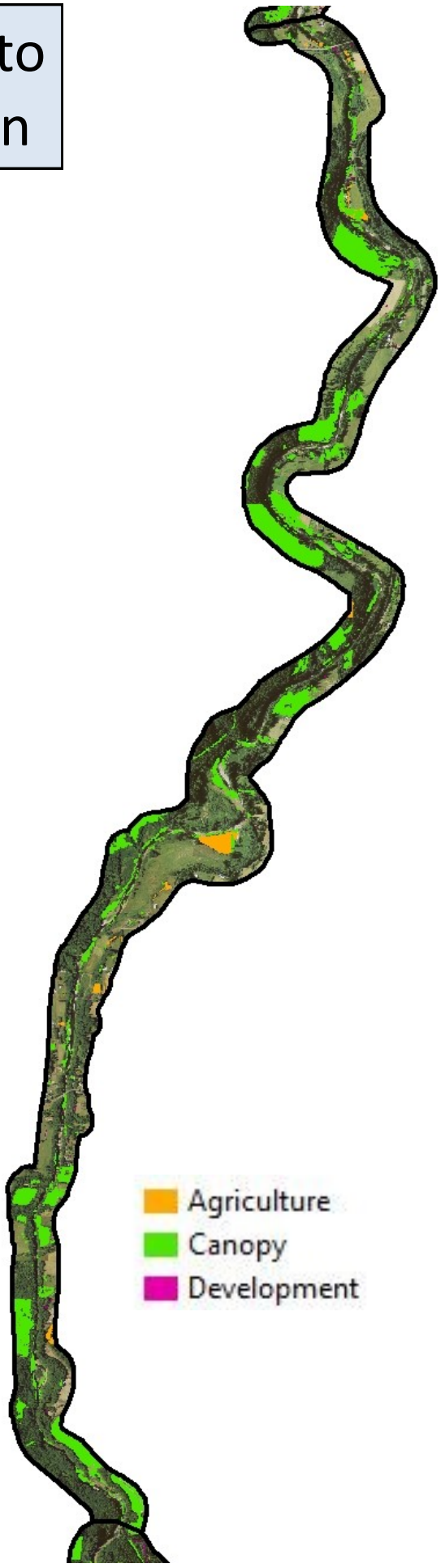
Segment 10: Elk Creek to Proposed Dam Location

Land Cover Losses

Losses represent areas that converted from the stated category (color-coded) to another category during one or more of the measured time periods.

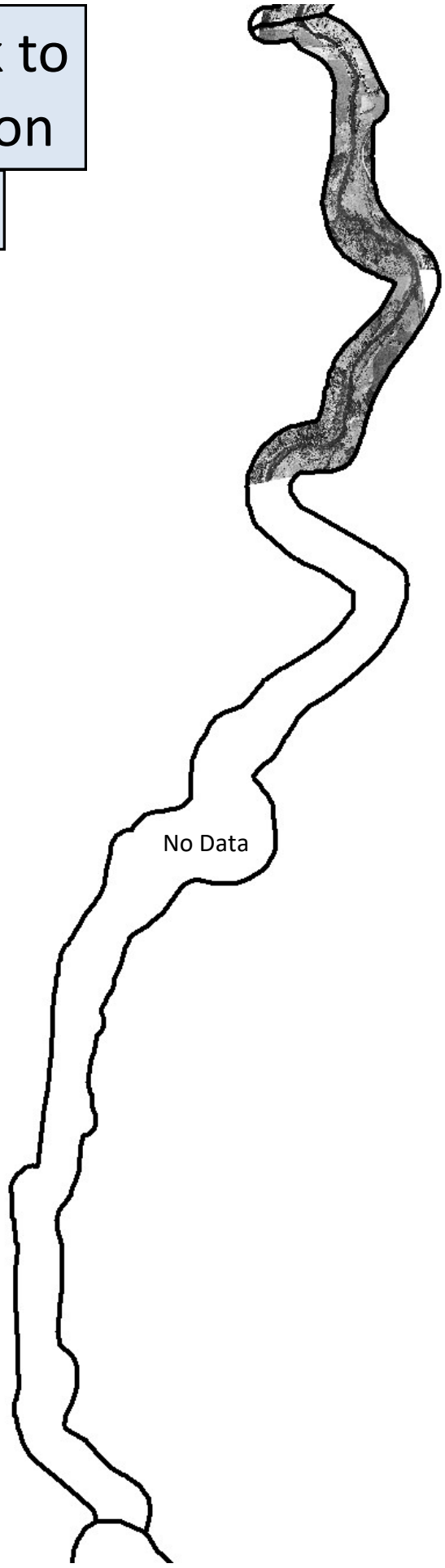
Losses (in acres)

Category	1938-1970s	1970s-1999	1999-2013
Agriculture	2.6	4.6	5.5
Canopy	1.9	129.0	44.3
Development	0.4	1.0	0.3



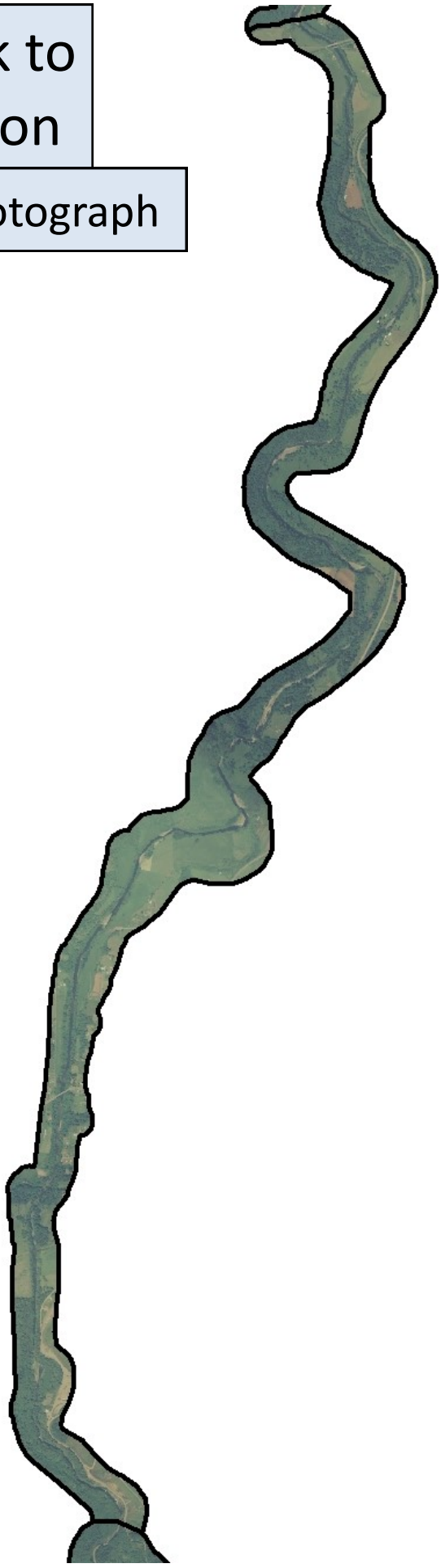
Segment 10: Elk Creek to Proposed Dam Location

1938 Aerial Photograph



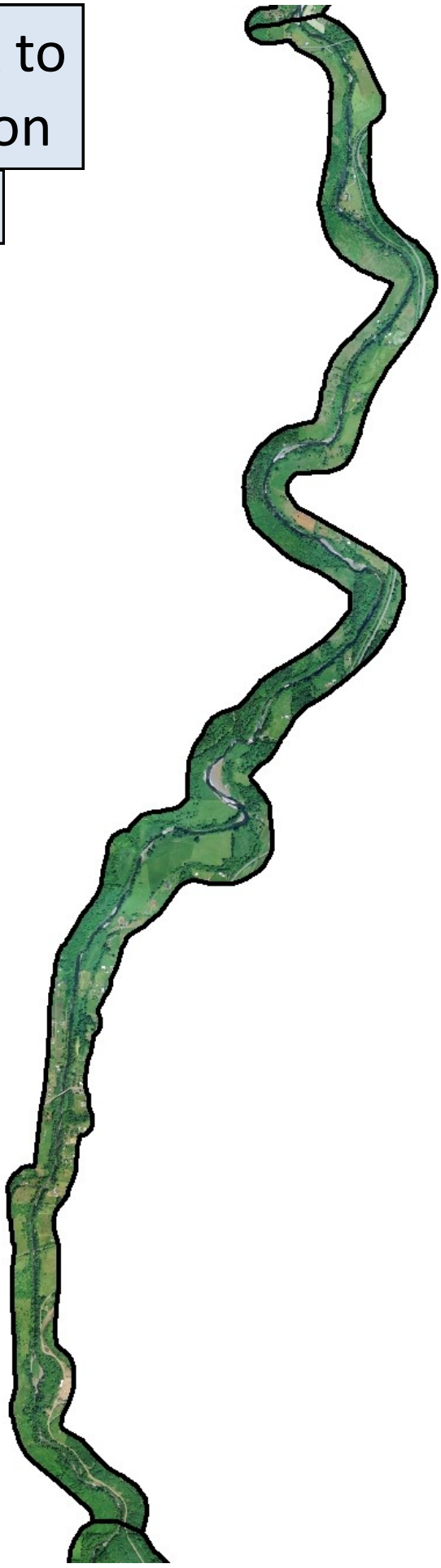
Segment 10: Elk Creek to Proposed Dam Location

1975/1978 Composite Aerial Photograph



Segment 10: Elk Creek to Proposed Dam Location

1999 Aerial Photograph



Segment 10: Elk Creek to Proposed Dam Location

2013 Aerial Photograph